CHALMERS
UNIVERSITY OF TECHNOLOGY

Urban potential in Bio-based Circular Economy

Literature review report

SHASWATI CHOWDHURY

Department of Architecture and Civil Engineering

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Research Group Environmental Geology – Management of land and water resources

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Gothenburg, 2020

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SUMMARY

Circular Economy (CE) will accelerate the emerging shift in resource consumption from finite to renewable and plants are key in enabling the switch as industries would opt more and more for resources with a bio-based origin. Cities have an important role in the process not only as the main consumers of the resources but also because vegetation provides numerous intangible ecosystem services essential for the wellbeing of urban dwellers. But the urban lands are heavily burdened with present activities and ongoing urbanization. Retrofitting the now obsolete and potentially contaminated brownfields provides an opportunity to engage bio-based land uses within the city periphery. At the same time, vegetation can be incorporated with Gentle Remediation Option (GRO), an alternative and more sustainable option over common 'dig and dump' remediation to eradicate the contamination concern and restore soil health. 'Opportunities of bio-based production in urban brownfields', a Ph.D. research project, concerns with such topics aiming to investigate the possibilities and preconditions for preparing urban brownfields urban bio-based production to foster a bio-based circular economy in the cities. This literature review is performed as part of the research effort to support and capture the wider scope of the project. The review work is focused on outlining the topics, 'CE', and 'urban brownfields'; and establishing a common ground merging these topics from where the rest of the research work can be based on. The novel concept (i.e. CE) are explored in this literature review together with the well-established topic (i.e. brownfields) to set the backdrop and their common subsets (i.e. cities in CE, urban land potential in bio-based CE) are further investigated to guide the review in delivering information necessary for the future project work. Urban Greenspaces (UGSs) and the ecosystem services (ESs) that can be derived from them are discussed as consecutively the potential bio-based land uses and the bio-based products in an urban setting. 14 UGSs are additionally explored to better understand the scope of ESS in the cities.

Key words:

Circular Economy (CE), Bio-based CE, Brownfields, Gentle Remediation Options (GROs), Bio-based land use, Urban Greenspaces (UGSs)

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PREFACE

This literature review has been carried out at the Department of Architecture and Civil Engineering, Division of Geology and Geotechnics at Chalmers University of Technology in Gothenburg, Sweden. The work has been supervised by Docent Jenny Norrman. This literature review is performed as part of research effort to support and capture the wider scope of the project ‘Opportunities of bio-based production in urban brownfields’, funded by the Swedish research council FORMAS (Grant number: 2017-00246).

Göteborg, Sweden.
December 2020

Shaswati Chowdhury

1 Introduction

This literature review is performed as part of research effort to support and capture the wider scope of the project ‘Opportunities of bio-based production in urban brownfields’, funded by the Swedish research council FORMAS. The aim of the project is to investigate the possibilities and preconditions for preparing *urban brownfields* urban bio-based production to foster a bio-based *circular economy* in the cities. As a transdisciplinary research project, several concepts (in italics in the previous sentence) of different disciplines are explored together and a clear state of the art understanding of the topics are necessary to maintain the relevancy of the research. It is also equally important to understand the scope of the topics for the future extension of current research or developing of new research interests in the same vein.

As a commencement of the research activity, this literature review focuses on outlining the topics, ‘Circular economy (CE)’, and ‘urban brownfields’; and establishing a common ground merging these topics from where the rest of the research work can be based on. The novel concept (i.e. CE) are explored together with well-established topic (i.e. brownfields) to set the backdrop and their common subsets (i.e. cities in CE, urban land potential in bio-based CE) are further investigated to guide the review in delivering information necessary for the future project work.

1.1 Background

Industrial revolution enforced an unprecedented change in the socio-economic system by providing methods that made possible mass production of goods (Prendeville et al., 2018; Winans et al., 2017). Economy has since grown exponentially pushed by the increased consumption rate; material consumption has risen by 800% in the past 100 years and is expected to triple by 2050 (Krausmann et al., 2009; S. Prendeville et al., 2018; UNEP, 2011). This has put an immense pressure on our already stretched planet’s resources and recent studies such as ‘Planetary boundaries’ outlines the graveness of the situation (Rockström et al., 2009; UNEP, 2011). It is getting clearer every day that earth’s ecosystem cannot sustain current economic system (UNEP, 2011; Wackernagel & Rees, 1998). To overcome the limitations of current ‘linear economy’ i.e. take-make-use- dispose- economy, the concept of a circular economy (CE) is considered as a solution encompassing both the prospect of economic growth and environmental protection (Lieder & Rashid, 2016; Winans et al., 2017). CE can be understood as production and consumption of material goods in a closed loop material flow and it aims to redefine growth by shifting economic activity from the consumption of finite resources towards the use of renewable ones (Ellen MacArthur Foundation, 2013; Sauvé et al., 2016). The concept of CE has been getting more and more traction worldwide with the help of promotion from organizations MacArthur Foundation among others (Winans et al., 2017). Governments, European Union (EU) for example, have also started to see CE as a comprehensive approach to achieve resource efficiency and as an answer to the rising material prices and climate change (COM/2011/0571, 2011; Domenech & Bahn-Walkowiak, 2019).

Cities are the driving forces behind the economic system and thus, are important actors in realising the CE agenda (Ellen MacArthur Foundation, 2020b). Half of the world population now urbanized and cities will represent the larger share of the global demographic which may increase up to 66%

by 2050 (United Nations, 2014; Wu, 2014). This transition will increase the enormous impact cities already exerts on the environment: the ecological footprints of the cities are often 500-1000 times larger as the urbanites depend on production of resources outside the city limits (Folke et al., 1997). Their large dependence on outsourcing makes cities exceedingly vulnerable, especially with the growing concerns over climate change (Parry, 2007; Prendeville et al., 2018). The growing challenges thus can be leveraged to enable the city managers to push for various urban sustainability agenda in different sectors (i.e. transportation, built environment, waste management, et.), holistically and as well as separately (Prendeville et al., 2018). CE in cities provides the opportunity to rethink the key urban systems and allow the exploration of new trajectories to ensure a degree of self-sufficiency and growing efficiency (Ellen MacArthur Foundation, 2020b).

With the growing adaptation of CE, the use of non-renewable resources; e.g. metals, oils, etc; for production will gradually decline. But the fate of lesser known non-renewable resources such as soil is not broadly discussed in CE (Breure et al., 2018). Not only soil provides the media of extraction for the finite materials, it also provides the surface for production of the main source of non-renewable material, vegetations (Breure et al., 2018). More and more products are resourcing their raw materials from bio-based sources and this will add on to the pressure on the agrarian landscape which are already stretched to its limits to provide for the growing world's population (European Commission, 2019a). Land in the city is in short supply due to massive demand from the rising needs but by retrofitting urban brownfields, the now obsolete urban lands that were previously exploited, can provide an opportunity to incorporate bio-based production within the city.

Urban brownfields are often centrally located, supported by existing infrastructure and often the only available option for redevelopment in the densely developed cities of Europe (Loures, 2015). The wastes of the linear land use system provide the scopes for urban regeneration and ecological restoration (Loures & Panagopoulos, 2007). But bringing brownfields back in use is both an extensive and expensive process complicated by the prospect of pollution from the previous activities. Greening is a flexible strategy that can substitute as an alternative process to regain soil health as well as increasing the much-needed vegetation cover in the dense urban fabric (Dickinson et al., 2000; Loures, 2015). With the many ecosystem services greenspaces already provide, they are also going to play a key role in the bio-based CE. But there remains a dominant restraint for using brownfields for bio-based production and that is the real or potential contamination problem due to previous uses (Hahn, 2013; U.S. EPA, 2011). The remediation of the brownfields thus needs to be discussed together with the development of brownfields for bio-based production. Vegetations and other bio-based technologies can alternatively use for remediation and risk management of the contaminated sites and have recently been in discussion for being relatively more sustainable than the other resource intensive technologies (Rosén et al., 2015a). Certain type of bio-based production such as cultivating energy crops, however, can take place regardless of the contamination status simultaneously reducing risks and improving soil quality (Enell et al., 2016).

1.2 Scopes and objectives

The overall aim of this literature review is to provide a state of the art theoretical foundation for the research project, 'Opportunities of bio-based production in urban brownfields' by providing an in-depth but inexhaustive understanding on the following topics: circular economy (CE), CE in cities, brownfields, and bio-based production. The specific objectives are:

- To give a general description of CE; the available frameworks and policies.
- To present a broad overview of how CE strategies is being and will be incorporated in cities, both from a macro and micro perspective.
- To further elaborate brownfields as part of urban land potential in CE; defining brownfields, remediation of brownfields, scopes of bio-based land uses on brownfields, and services that can be derived from the said land uses.

1.3 Structure of the report and the limitations

The structure of the report is presented as a flow diagram in figure 1.1. *Chapter 1* gives a brief background of the topic, setting up the objectives for the literature review, and reveal the structure along with the limitations. CE is the main discourse of *chapter 2*. In this chapter, origin and definitions of CE are discussed first followed by exploration of different CE frameworks. The chapter is concluded with a brief description of the CE policies in practice in two different socio-political regions: Europe and China. *Chapter 3* discusses cities from the CE perspective, both in macro and micro scale. In macro scale, how CE can be adapted in a city as an entity is discussed from the knowledge development and stakeholder adaptation perspectives. In micro scale, essential service infrastructures; food, transportations, and built environment, are discussed separately to illustrate the possibilities, practices, and limitations of adopting CE strategies in different components of the sectors. Urban land potential in CE from the perspective of retrofitting brownfields is dug a bit deeper in the *chapter 4*. Policy development with regards to different contextual development of concerns over brownfield in the US and in Europe is discussed first. It is followed by a brief discourse on the remediation processes of brownfields from the prospect of time and resources with Gentle remediation options (GROs) being detailed out further as a sustainable substitute. Bio-based land use alternatives to be developed on brownfields to foster bio-based CE in cities are discussed as part of urban green infrastructure. The ecosystem services (ES) that can be derived from the green land use alternatives are elaborated as prospective bio-based products that urban greens have to offer. The literature review than ends with providing a discussion and conclusion.

The main limitation of this report is that the literature reviewed are rather targeted than being extensive for certain topics to give a justified overview rather than the full picture. Since CE is a rather new topic, peer reviewed articles are few and far between, so a lot of grey literatures from government's policy documents to industry's sustainability strategies are reviewed for collecting information.

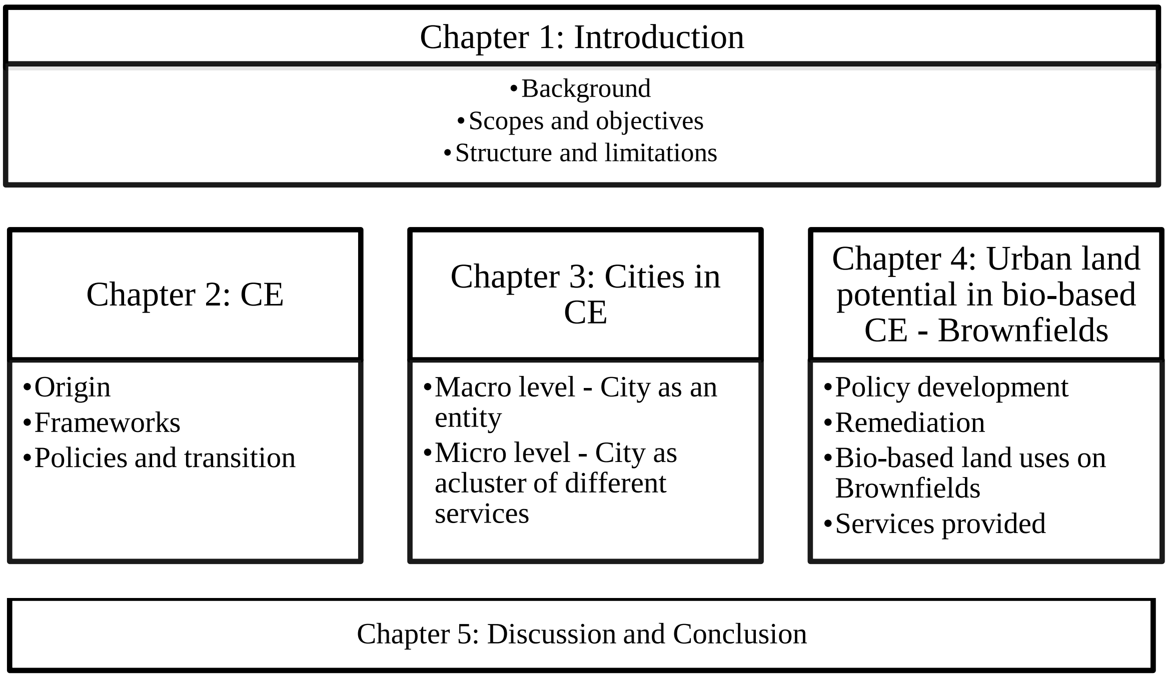


Figure 1-1: The structure of the literature review report

2 Circular Economy (CE)

Current economic system is fundamentally ‘linear’ for most parts; following the same model of ‘take-make-dispose’ resource exploitation since the industrial revolution (Ellen MacArthur Foundation, 2013). The impact of this relentless consumption of earth’s finite resources coupled with explosive population growth is that this planet may soon, if not already have, will reach its carrying capacity of the human race (Pengra, 2012; Sauvé et al., 2016). Moreover, there are now empirical evidences that humans are the main influencers of the global temperature rise with greenhouse gas emission being the anthropogenic driver (IPCC, 2014). Concerns were voiced early on as well; the Brundtland report (Brundtland Commission, 1987) highlighted the need for sustainable development balancing between economy and ecology, while ‘Limits to growth’ (Meadows & Club of Rome, 1972) explored population growth and natural resource use scenarios to impose limits to industrial growth. However, starting from the current millennium, more and more companies has begun to notice the risk of the linear system for their own business practices, such as higher resource prices and unpredictable resource availability (Ellen MacArthur Foundation, 2012; Prendeville et al., 2018; Sauvé et al., 2016; UNEP, 2011)

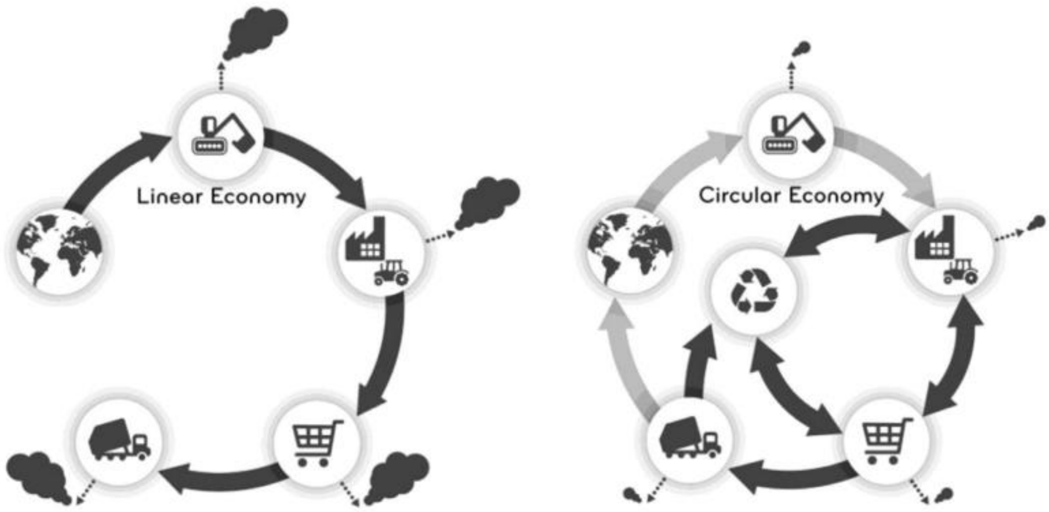


Figure 2-1. Linear economy vs. Circular Economy; from Sauvé et al. (2016).

Circular Economy (CE) is an alternative concept that takes place in a loop where resources are in circular movements within a system of production and consumption (figure 2-1). The objective of CE is to optimize the use of raw materials and energy through multiple phases, and reduce pollution and waste at each step (Sauvé et al., 2016). CE is considered a solution for balancing ambitions for economic growth and environmental protection and thus, as a mechanism to implement the Sustainability Development Goals. CE currently holds the most credibility among other sustainability operationalizing tools such as green economy and green growth and its popularity is rising among policymakers as well as researchers (Ghisellini et al., 2016; Kirchherr et al., 2017).

2.1 Origin of CE concept

There is no one origin of the CE concept; different researchers (Ellen MacArthur Foundation, 2018a; Prendeville et al., 2018; Winans et al., 2017) reached different conclusions about the source of inspiration for CE. These three group of researchers however, agree on two things; one is that the concept of circularity is not a novel development but has appeared in many forms throughout the history, and second is the importance of William McDonough and Micheal Braungart's book 'Cradle to Cradle' in the development of the CE concept. The sources of inspiration for CE based on the reviews done by Ellen MacArthur Foundation (2018a), Prendeville et al. (2018), and Winans et al. (2017).

2.1.1 Cradle to Cradle

German chemist Michael Braungart and American architect Bill McDonough envisioned a world without waste and published their philosophy in the book 'Cradle to Cradle: Remaking the way we make things' in 2002. The authors built on the original concept and created Cradle to Cradle™ certification process for products in 2010 (Braungart & McDonough, 2009; C2C, 2018). Cradle to cradle discards the conventional 'less bad' eco-efficient approach where efforts are put into minimizing impacts on the environment for not being 'good enough'. Focusing mainly from the perspective of the product design, the Cradle to Cradle approach considers waste generation as a design flaw as all material are finite, and interprets 'waste equals food' as the value that can be collected and recovered from waste (Toxopeus et al., 2015). The authors promote the use of renewable energy and highlights the importance of variety that can be found in natural system rather than the industrial uniformity. Successful implementation of the concept is depending on good stakeholder relationships and social responsibility (EPEA, 2018). (Further elaborated in section 2.3.2)

2.1.2 Other sources of origin of CE

Researchers have gathered source of inspiration for CE from as early as 1862 (S. Prendeville et al., 2018). The concept of a closed loop system appeared via several thought process, from waste recycle to natural solution (Biomimicry Institute, 2018; Frosch & Gallopoulos, 1989). Winans et al. (2017) also argues Rachel Carson's book 'Silent Spring' as an inspiration because of its wide spread acceptance for mainstreaming environmental concern. Prendeville et al. (2018) and The MacArthur Foundation (2018) presents a similar set of sources for CE that mainly focuses on economic systems. A brief introduction of the inspirations is provided in Table *2-1*.

Table 2-1. List of source and inspiration according to Winans et al. (2017), S. Prendeville et al. (2018)and Ellen MacArthur Foundation (2018).

Source	Brief explanation
Work of Peter Lund Simmonds	-Published on 1862 (Simmonds, 1862). -Mentions the lack of a system to capture the waste products and stresses on the need for innovation to innovation to generate wealth from waste such as food by-products in large cities (Cooper, 2011; S. Prendeville et al., 2018). -Simmonds's body of work deals with 'waste', 'waste products' and 'waste utilisation'(Cooper, 2011; S. Prendeville et al., 2018).

‘Silent Spring’ by Rachel Carson	-Published on 27 September 1962(Carson et al., 2002). -Documents the impact of pesticides, particularly DDT, on the environment and provided empirical evidences for her claim (Griswold, 2012). -Bolstered the environment movement across the general public and unified separate conservation movements across USA under one unanimous claim of environmental protection (Griswold, 2012; Skelly, 2017). -US EPA (United States Environment Protection Agency) was founded in the 1970 and credits Silent Spring as the driving force (US EPA, 2018).
Spaceship earth metaphor	-Spaceship earth metaphor envisions earth as a spaceship and all the humanity as a crew who needs to work together for the greater good of the vessel (BFI, 2018). -Popularised in academia by Kenneth. E. Boulding in his essay ‘The Economics of the Coming Spaceship Earth’ published in 1966 (Boulding, 1966). -Earliest known use by Henry George in 1892, later used by George Orwell and Buckminster Fuller(Environmental Encyclopedia, 2018; Kalen, 2010).
‘The Limits to Growth’ by Club of Rome in 1970	-Published in 1972 (Meadows & Randers, 2012). -Club of Rome consists of a group of international business, state and scientific leaders (Club of Rome, 2018). -Authors noted that the resources are plummeting due to population growth and destructive industry (Meadows & Club of Rome., 1972). -With the ongoing trend, the authors put a 100-year limit on the growth on earth (Meadows & Club of Rome., 1972).
Works of eco-economist Herman Daly	-Pioneer of Ecological economics and Originator of Steady-state Economy by publishing the book, ‘Toward a Steady-state Economy’ in 1973 (Daly, 1973). -Credited with getting the World Bank to think about sustainable development in the early 1990s (European Commission, 2013).
Performance Economy Concept by Swiss architect W. R Stahel and G. Reday	-Walter Stahel and Genevieve Reday first presented visions on an economy of loops in their 1976 research report to the European Commission 'The Potential for Substituting Manpower for Energy' (Ellen MacArthur Foundation, 2018a; Reday-Mulvey, 1977). -Later in the book ‘The Performance Economy’, W. Stahel explains the concept as a strategy to turn technological advancement in to a profitable business model (Walter R. Stahel, 2010). -Stahel is also credited for coining the phrase ‘Cradle to Cradle’ (Ellen MacArthur Foundation, 2018a).

Industrial Ecology	-A paper titled 'Strategies for Manufacturing', published on 1989 first introduced Industrial Ecology where industrial system is conceptualized as an ecosystem (Frosch & Gallopoulos, 1989). -The subtitle further explaining their intention, 'Waste from one industrial process can serve as the raw materials for another, thereby reducing the impact of industry on the environment' (Frosch & Gallopoulos, 1989). -Industrial Ecology studies material and energy flow within the industrial system and aims at creating a closed loop process (Ellen MacArthur Foundation, 2018a). -This framework is often referred as the 'science of sustainability'(Ellen MacArthur Foundation, 2018a).
Biomimicry concept	-The term was popularized by Janine Benyus in her book 'Biomimicry: Innovation Inspired by Nature' published in 1997 (Biomimicry Institute, 2018). -Biomimicry is the concept of studying nature and mimicking its form, process and system to solve human problems (Ellen MacArthur Foundation, 2018a). -The three-key principle of Biomimicry are- nature as model, nature as measure, nature as mentor (Ellen MacArthur Foundation, 2018a).
Natural Capitalism	-The book "Natural Capitalism: Creating the Next Industrial Revolution" by Paul Hawken, Amory Lovins and L. Hunter Lovins was first published on 1999 (Hawken, Lovins, & Lovins, 2010). -Natural Capitalism as opposing to Industrial Capitalism describe a global economy dependent on nature (NatCap, 2018). -In this concept, business and environmental interests overlap, recognising the interdependencies that exist between the production and use of human-made capital and flows of natural capital (Ellen MacArthur Foundation, 2018a).
Blue Economy	-Zero Emissions Research and Initiatives (ZERI) was established by former Ecover CEO and Belgian businessman Gunter Pauli in 1994 at The United Nations University with the help of Japanese Government (ZERI, 2018) -Guntar Pauli and his team summarized 340 innovations that could function as an ecosystem and presented in a book, 'The Blue Economy' which was accepted as a report to The Club of Rome in 2009 (Club of rome, 2018) -Based on 21 founding principles, the Blue Economy primarily focuses on solving problems with solutions determined from the local environment and physical/ecological characteristics (Ellen MacArthur Foundation, 2018a; The Blue Economy, 2018).

2.2 Defining CE

The definition of CE provided by the Ellen MacArthur Foundation seems to be the most adapted among several other available definitions (Geissdoerfer et al., 2017). Their report on CE in 2013 is considered influential in promoting the discourse of CE in Europe. Their definition for CE stands:

> 'The circular economy refers to an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises, tracks, and eliminates the

use of toxic chemicals; and eradicates waste through careful design' - Ellen MacArthur Foundation, 2013.

China was one of the first nations to accept CE formally in 2002 and various research projects on this topic has since been funded by the government at different levels. Chinese government describes CE as "realization of a closed loop material flow in the whole economic system" (Geng & Doberstein, 2008).

The European Commission (EC) has adopted a CE package in January 2014. Their definition stands (EC, 2018):

- In a circular economy, the value of products and materials is maintained for as long as possible.
- Waste and resource uses are minimised, and when a product reaches the end of its life, it is used again to create further value.
- This can bring major economic benefits, contributing to innovation, growth and job creation

Despite CE being a relatively new field, available CE definitions vary considerably in their content, size, and audience. Kirchherr et al. (2017) identifies this as a serious challenge for any researcher working on this topic because the abundance of the definitions makes CE hard to conceptualize. In their paper, they analysed 114 definitions gathered from scholars (peer-reviewed journals) as well as practitioners (policy papers and reports) to produce one definition that captures the core principle, aim and enablers of CE separately and they hope it will serve as a conceptual foundation for the future work. They define CE as:

- An economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes.
- It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations.
- It is enabled by novel business models and responsible consumers.
  (Kirchherr et al., 2017)

2.2.1 The R framework

The 3 Rs; reduce, reuse and recycle, originates from the waste hierarchy but the concept varies from country to country. The Kyoto Workshop in 2009 united the researches and policy makers of countries which had adopted the 3R framework in their waste management, where they came together to compare data to create a comprehensive system (Sakai et al., 2011). China later adopted 3R as the core principle of implementing CE (Yang, Zhou, & Xu, 2014). EU on the other hand, adopted 4R, adding Recover, as the main policy framework (Kirchherr et al., 2017). The 4R framework is explained in the table 2-2.

Table 2-2: 4R Framework, adapted from Hu et al., 2011

Level 1: Reduce	Reduce the consumption of resource and the production of wastes in the processes of production, circulation, and consumption.
Level 2: Reuse	Use the wastes as products, either in the same function or in another.
Level 3: Recycle	Use the wastes as raw materials after simple treatment such as collection, separation and suitable modification, during which core physical and chemical properties should remain.
Level 4: Recover	Use the wastes as products, or raw materials after technical treatment during which the core physical or chemical properties change in relation to the feeding condition

The R framework continue to evolve and as far as 9Rs have been developed. Waste hierarchy is becoming less featured and CE is more moving towards system perspective (Kirchherr et al., 2017; Potting, Hekkert, Worrell, & Hanemaaijer, 2017) (figure 2-2).

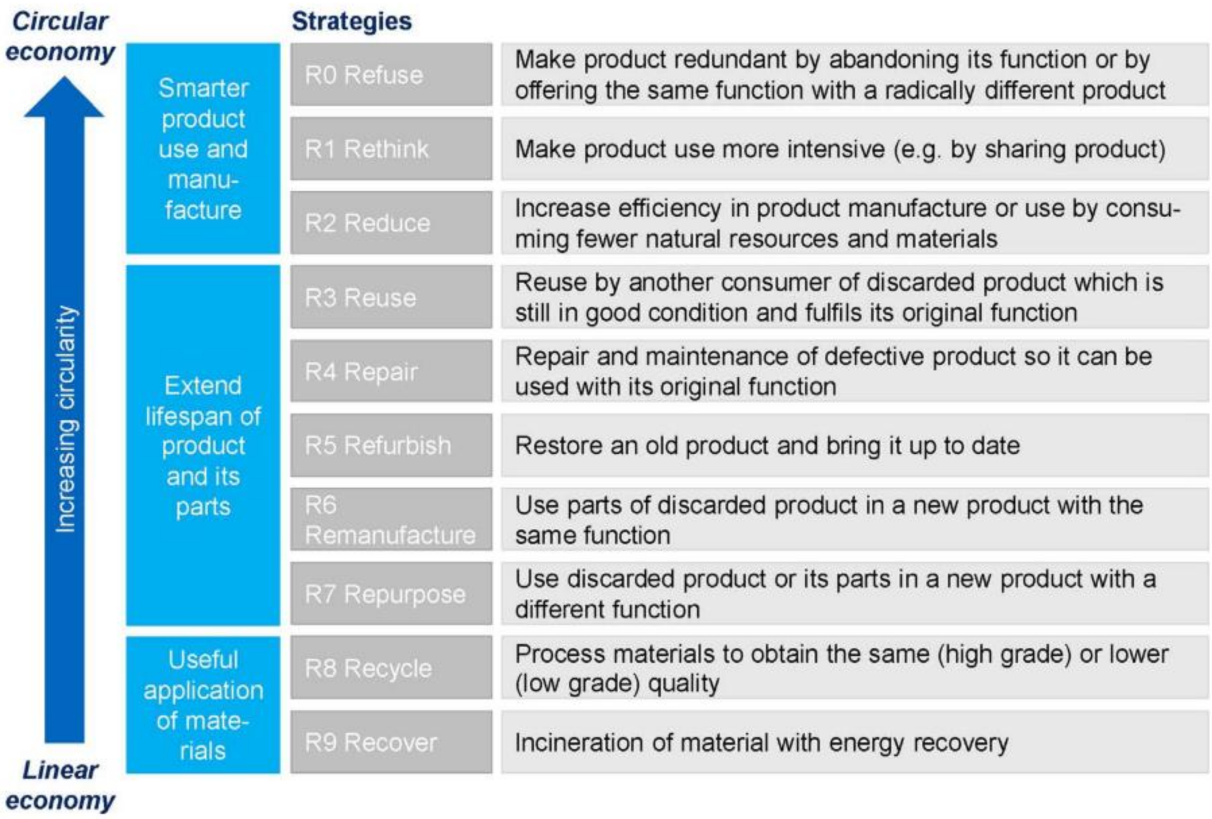


Figure 2-2. The 9R framework; from Kirchherr et al. (2017).

2.2.2 Cradle to Cradle (C2C) Framework: Technical cycle and biological cycle

Braungart and McDonough first established Cradle to Cradle (C2C) concept in their famous book 'Cradle to Cradle: Remaking the way we make things' and elaborated the concept further in the book, 'The upcycle: Beyond sustainability – designing for abundance' (Braungart & McDonough, 2009; McDonough & Braungart, 2013.; Wautelet, 2018). The authors are critical about the eco-efficient approach which only reduces the ecological impact of businesses in short term. They present the concept of eco-effectiveness as an alternative positive agenda that maximises the ability of production processes by harmonizing with the natural and human environment (Braungart & McDonough, 2009) (figure 2-3).

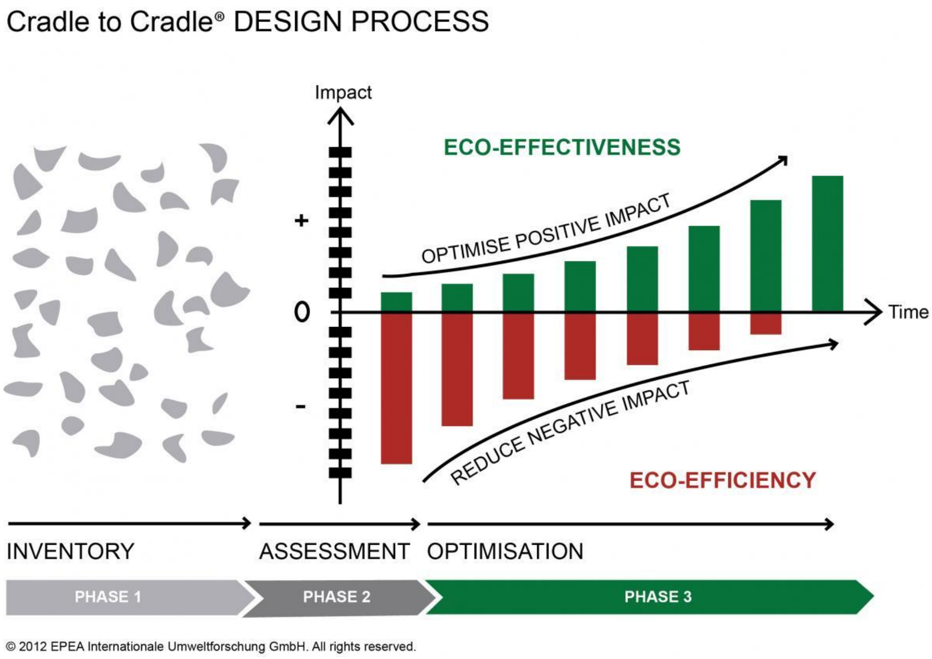


Figure 2-3 Cradle to Cradle (C2C) design processes; from Braungart EPEA (2018).

Braungart and McDonough argue that waste is a predominantly human concept as the natural processes have no waste. C2C considers generation of waste as a design flow and considers all materials as nutrients that should be allowed to flow within the nutrient cycle (Braungart & McDonough, 2009; Wautelet, 2018). There are two cycles or metabolism for nutrients; biological and technical (figure 2-4)

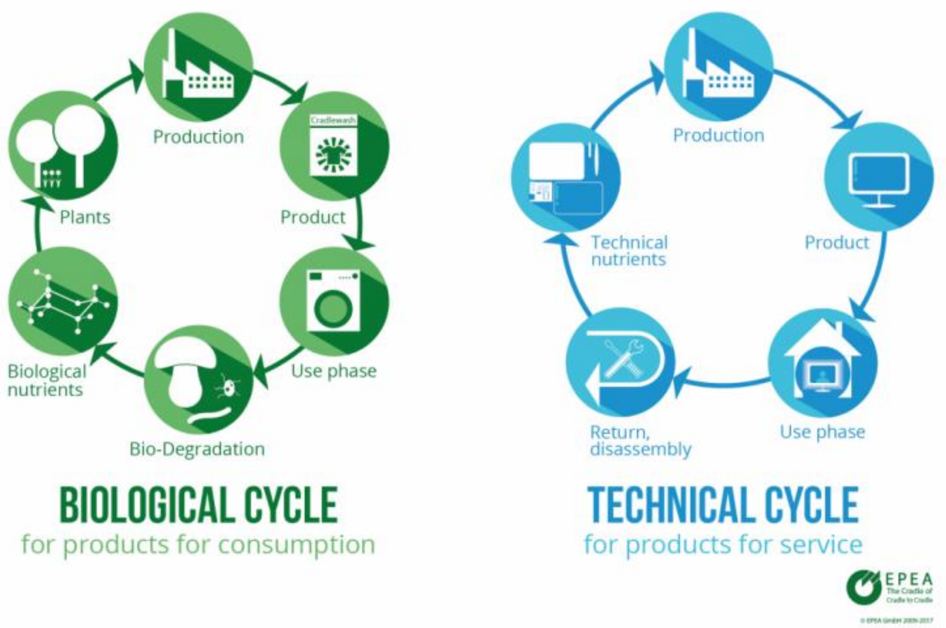


Figure 2-4: Biological and technical cycles in C2C design; from EPEA-Hamburg (2020).

Products are also grouped in to three types based on their use in C2C: products of consumption, products of service and unmarketable products. Products of consumption (i.e. cleaning chemicals, shampoo, textiles etc.) are made from biological nutrients and should be designed ensuring the safe return of the nutrients in the biological cycle. Products of services are made of technical nutrients both synthetic and mineral (i.e. cars, washing machines, televisions etc.) (Braungart EPEA, 2018; Wautelet, 2018). The nutrients of these products should be recycled after use and circulate within a closed loop system; the technical cycle or metabolism (Braungart EPEA, 2018; Wautelet, 2018). Unmarketable products are hazardous residues that cannot be consumed or be returned in the environment in a safe way and should be discontinued and replaced immediately (Braungart EPEA, 2018).

2.2.3 ReSOLVE Framework

Ellen MacArthur Foundation (2015) identifies three key principle of CE from the Cradle to Cradle framework (also figure 2-5):

- **Preserve and enhance natural capital**
  by controlling finite stocks and balancing renewable resource flows—for example, replacing fossil fuels with renewable energy or using the maximum sustainable yield method to preserve fish stocks.
- **Optimise resource yields**
  by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles – for example, sharing or looping products and extending product lifetimes.
- **Foster system effectiveness**
  by revealing and designing out negative externalities, such as water, air, soil, and noise pollution; climate change; toxins; congestion; and negative health effects related to resource use.

They then translate these three key principles into an action framework for implementing CE. The six business actions are: Regenerate, Share, Optimise, Loop, Virtualise, and Exchange – together, the ReSOLVE framework (Table 2-3).

The six actions individually present opportunities for a major business opportunity that would help diverge from the linear to the circular path. The ReSOLVE framework considers both business and country perspective and aims to be a tool to initiate growth by implementing circular strategies. Table 2-3 below explains the 6 actions separately supported with example activities, business implementation, and literature.

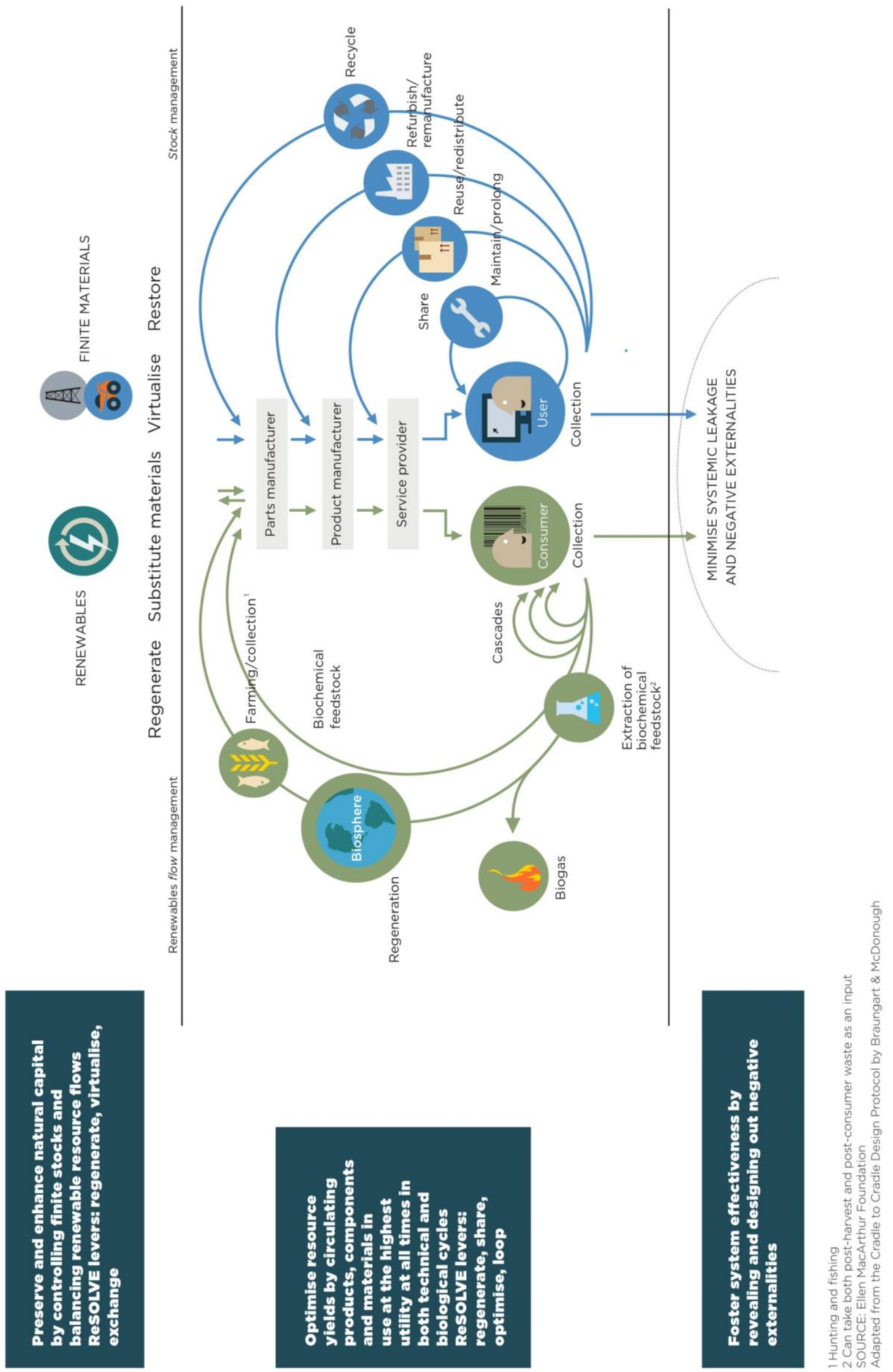


Figure 2-5: Circular Economy principles; from Ellen MacArthur Foundation (2015).

Table 2-3: The ReSOLVE model adapted in context of sustainability literature, adapted from Ellen MacArthur Foundation, 2015; S. Prendeville et al., 2018.

CE principle	Example business activities	Literature covering these topics	Example of Business implementation
Regenerate	Shift to renewable energy and materials Reclaim, retain and restore health of ecosystems Return recovered biological resources to the biosphere	Bocken et al.,2014; Braungart & McDonough, 2009 Braungart & McDonough, 2009 Braungart & McDonough, 2009	European renewable energy investment – USD 59.8 billion in 2015-16 2.5 million hectares of lands regeneration worldwide by The Savory Institute and seeks to influence up to 1 billion hectares by 2025
Share	Share assets (e.g. cars, rooms, appliances)	Cohen & Muñoz, 2016; Schalteggeret al., 2016	Car sharing: Apps- BlaBlaCar, Lyft, Companies- BMW and Sixt's dripve 'Drive by the minute' House sharing: AirBnb
Optimize	Prolong life through maintenance, design for durability, upgradeability, etc. Increase performance/efficiency of product Remove waste in production and supply chain Leverage big data, automation, remote sensing and steering	Bakkeret al., 2016; Prendeville et al., 2017; Salvia, 2016 Peck et al., 2015; Stahel, 2010 Bocken et al., 2014 Stahel, 2010	Lean philosophy of Toyota
Loop	Remanufacture products or components Recycle materials Digest anaerobically Extract biochemicals from organic waste	Von Weizsäcker et al., 1997 Stahel, 1982 Pan et al., 2014 Mohan et al., 2016	For finite materials: Caterpillar, Michelin, Rolls Royce, Philips or Renault For renewable materials: The Plant - closed loop, zero-waste food production located in Chicago
Virtualize	Dematerialize directly (e.g. books, CDs, DVDs, travel) Dematerialize indirectly (e.g. online shopping)	Druckman & Jackson, 2010; D. Meadows & Randers, 2012; Von Weizsäcker et al., 1997 Von Weizsäcker et al., 1997	E-book, online shopping, autonomous vehicles (Google, Apple, and most OEM), virtual offices etc.
Exchange	Replace old with advanced, renewable materials e.g. Mycelium Apply new technologies (e.g. 3D-printing) Choose new product/service (e.g. multimodal transport)	Lacy & Rutqvist, 2016 Ford & Despeisse, 2016 Stahel, 2010	3D printing or electric engines, multimodal transport

2.2.4 Top-down and Bottom-up Framework

Lieder & Rashid (2016) builds on their review of 156 relevant CE articles and argues that CE literature falls short in providing a comprehensive framework for CE. A comprehensive CE framework, they explain, should consist of the three perspectives, economic benefits, resource scarcity, and environmental impact (Figure 2-6).

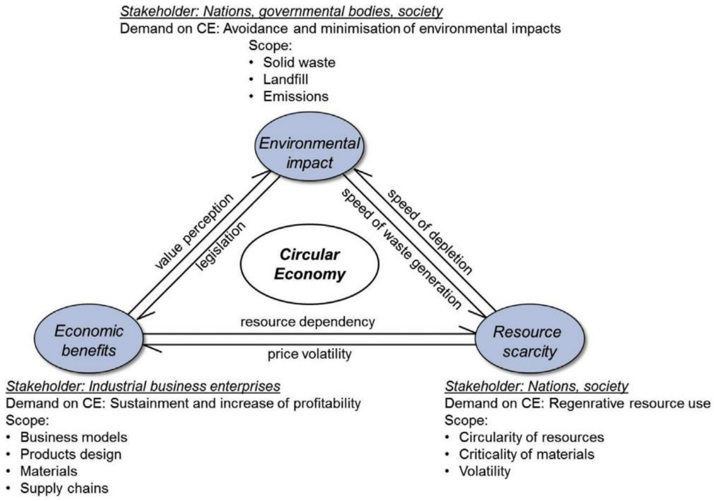


Figure 2-6: A comprehensive CE framework proposed by Lieder & Rashid, 2016.

Industries drive for economic benefits and they depend on resources to operate; hence their performances are sensitive to issues such as resource price volatility and supply risk. The industries' impact on the environment at the same time is apparent if the linear 'end of life' production is carried on. The products become waste and the resource depletion forces legislation on industries operation. In CE however, waste is resources and they can recycle back to the production. The authors assume based on the previous explanation that the production of waste generation and waste depletion will be reduced in CE compared to linear economy.

Despite few success stories of CE implementation, the authors think there needs to be a radical change for a large-scale implementation on industry manufacture requires commitments of the higher management. Assuming there's inverse motivation among stakeholders, they suggest a concurrent approach that aligns interests by operating top-down through public institutions and from bottom-up through industries (figure 2-7).

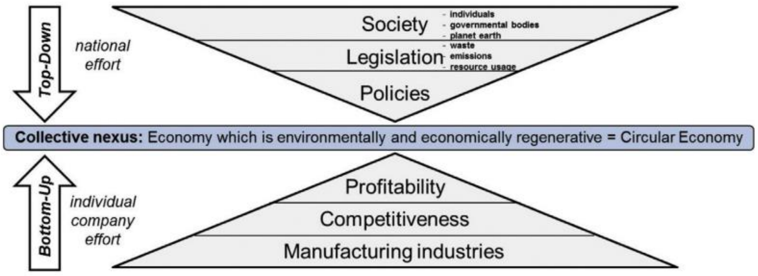


Figure 2-7: CE implementation strategy applying Top-down and bottom-up approach proposed by Lieder & Rashid (2016).

2.2.5 Value Hill framework

The Value Hill framework for circular business strategy is created by a collaboration between Sustainable Finance Lab[1], Circle Economy[2], Nuovalente[3], TUDelft[4] and het Groene Brien[5] (Circle Economy, 2018b). In their paper, Achterberg, Hinfelaar, & Bocken (2016) explains the use of the framework as a tool for companies to position their companies in a circular context and also works as an overview of the circular partners and collaborators needed for a successful circular value network.

The Value Hill categorises a product's lifespan in three phases: pre-use, in-use and post-use (Circle Economy, 2018b). The pre-use phase consists of 4 steps: resource extraction, manufacture, assembly and retail, and value is added as the product moves 'uphill' (left side of the slope, see figure 2-8) and reaches the second phase, in-use. Users buy the product at its highest value point and the product stays at the top of the value hill as long it is in use. The third phase is the last one, post-use phase where the product loses its value as it moves downhill. In linear economy, the value of the product destroys quickly after the consumer use (right side of the hill, see figure 2-8) and ends up in landfills or are incinerated. Products are also designed to be short lived as linear business models benefit from selling as many products as possible (Achterberg et al., 2016).

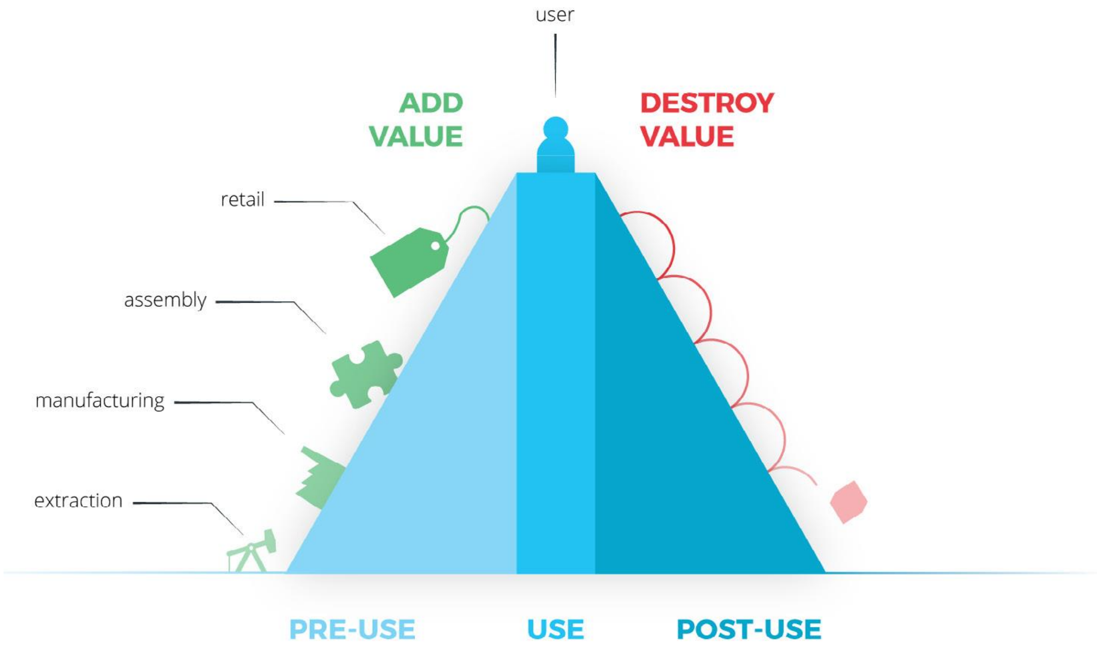


Figure 2-8: Linear Economy in the Value Hill Framework; from Achterberg et al. (2016).

[1] Informal interdisciplinary network of mostly academics of different Dutch universities (Sustainable Finance Lab, 2018)
[2] A social enterprise, organised as a cooperative, working towards transition to circular economy (Circle Economy, 2018a)
[3] A network of innovators and experienced professionals providing strategies and support for sustainability agenda (Nuovalente, 2018)
[4] Delft University of Technology (TUDelft, 2018)
[5] Network of 130 scientists aiming to support entrepreneurs working towards sustainable economy (The Green Brain, 2018)

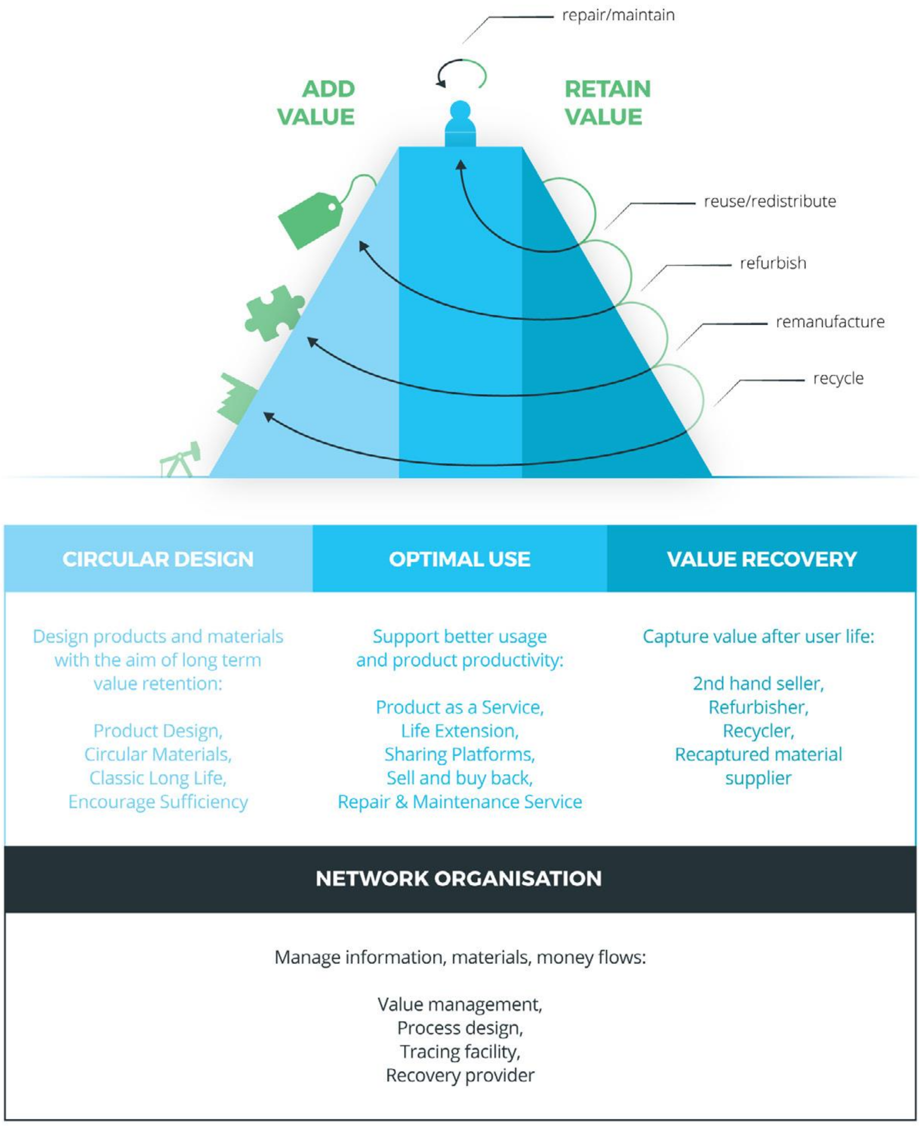


Figure 2-9: Circular Economy in the Value Hill Framework; from Achterberg et al. (2016).

Circular business models on the other hand, allows product to remain in use longer thus extending its stay at their highest level of value as long as possible. In the context of Value Hill, products designed for circularity stay longer at the top of the hill and it is achieved by developing products that lasts longer and are suitable for maintenance and repair. The downhill journey is slowed down as much as possible by retaining the useful resources of the product and feeding it in different uphill phases (see figure 2-9). Products can move back up in the Value Hill as it is (reuse/redistribute) or can be separated in to components to add back on the previous phases (Achterberg et al., 2016).

2.2.6 Circular economy framework to assess circular projects and businesses

The Ellen MacArthur Foundation (2013) identifies four building blocks to move from linear economy to a circular one- reverse cycles and cascades, circular product design and production, innovative business models, and cross-sector collaboration. Kraaijenhagen et al. (2016) elaborate in their book ‘Circular Business: Collaborate and Circulate’ that it’s the fourth block, collaboration, where the practical support is lacking, and they argue the inevitability of the role of collaboration in building economy. Circular Economy in their definition is ‘an economy in which stakeholders collaborate in order to maximize the value of products and materials, and as such contribute to minimising the depletion of natural resources and create positive societal and environmental impact’ (Kraaijenhagen et al., 2016).

Aside from the innovative material use and product design, Kraaijenhagen et al. (2016) stresses on the importance of collaboration both internal collaborations within the organisation and external with partners in value chain and customers. System thinking is discussed as a way of implementing circular thinking in business model. They propose a framework that combines the technical, collaboration and business model aspects to evaluate the circular strategy adapted in projects and businesses (figure 2-10). In the book, ‘Circular Business: Collaborate and Circulate’, the authors use this framework to assess existing circular practices such as Fairphone[6], Bugaboo flex plan[7], Michelin pay per kilometre[8], etc. Furthermore, Kraaijenhagen et al. (2016) back up the framework with a 10-step approach for business and organizations that wants to adopt a circular strategy (figure 2-11).

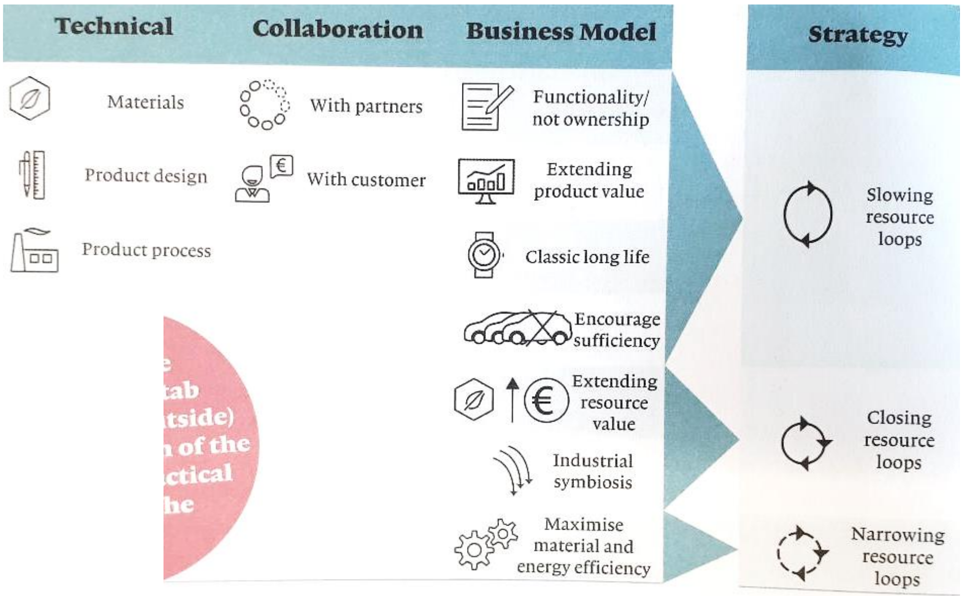


Figure 2-10: Framework to assess circular projects and business; from Kraaijenhagen et al. (2016).

[6] Modular smartphone makers based in Amsterdam, Netherlands focusing on easy repair and maintenance; available at: https://www.fairphone.com/en/our-goals/?ref=header

[7] The Dutch company specialising in mobilizing products specially for infants and toddlers; along with their modular design, they also tested ‘Flex plan’ of leasing stroller instead of selling and later, refurbishing. More at https://www.rescoms.eu/case-studies/bugaboo

[8] The French tiremakers offers pay per kilometer where tires are fitted with RFID chip for mileage detection; more at https://www.michelintruck.com/services-and-programs/michelin-fleet-solutions/ and https://www.thehindubusinessline.com/companies/michelin-may-look-at-leasing-tyres-to-indian-truck-owners/article27891082.ece.

Figure 2-11: Ten steps towards circular business; from Kraaijenhagen et al. (2016).

2.3 Policies and transitions

Circular Economy (CE) has prominent influence in both European and Chinese policy making (Ghisellini et al., 2016; McDowall et al., 2017). In both region, CE is perceived an embodiment of ecological modernization to overcome the conflicts between environment and economy through technical and social innovation. But while China broadly covers pollution and other issues under the CE umbrella, Europe limits its scope to waste, resource and business models (McDowall et al., 2017).

2.3.1 Chinese model

China has adopted the Opening and Reform policy in 1978 and developed rapidly to become the world's largest manufacturer and exporter at present (Bank & Development Research Center of the State Council, 2014; Ellen MacArthur Foundation, 2018c; We & Lin, 2016). The gross domestic product (GDP) of the most populous country of the world also saw a rapid acceleration. In 2012 alone, China's GDP accounted for 11.6% of the total global GDP and the percentage is increasing (We & Lin, 2016). But at the same time, the resource efficiency is lacking for a country that has the lowest per capita resources; it consumed 21.3% of energy, 54% of cement, and 45% of steel in the world at the same time (Mathews & Tan, 2016). Coupled with the environmental pollution, China was pushed to rethink its economic structure to maximise its limited resources (We & Lin, 2016).

Chinese scholars have been promoting CE to tackle the environmental and economic challenges since 1990s being inspired by the industrial ecology and cleaner production concepts popularized in the Europe, the USA and Japan (Ellen MacArthur Foundation, 2018b; Pan et al., 2014). The Harmonious Development goal of Hu Jintao's administration (2002–2012) that aims to balance policy by taking account to environmental, social and economic objectives has coining interest with CE concept (McDowall et al., 2017). The State Environmental Protection Administration (SEPA) promoted the CE concept specifically for the planning and operation of eco-industrial parks in 2002 and the state council (Geng et al., 2009). In 2008, Circular Economy Promotion Law was passed in congress to provide national-level framework for pursuing CE (Pan et al., 2015; We & Lin, 2016).

China's CE is primarily based on the principle of 3R framework; reduce, reuse and recycle and focus is primarily on reduce. CE policies mainly focuses on upgrading industrial structures, cleaner production, recycling and comprehensive utilisation of waste materials, and exploitation and utilisation of resources and energy; consumers and consumption pattern on the other hand has little to no emphasis (McDowall et al., 2017; We & Lin, 2016). Key tools for implementation include command-control, tax, fiscal, financial, and pricing measures (We & Lin, 2016). A three-layered approach was adopted to ensure a scaled implementation of CE: micro (firm level), meso (eco-industrial park) and macro (city or province) (McDowall et al., 2017; Yuan et al., 2008).

At micro level, industries are pushed to adopt a cleaner production strategy (e.g. pass ISO14001 certification) are encouraged to conduct cleaner production auditing (Geng et al., 2009; Yuan et al., 2008). Local environment protection bureaus are required to publish to the public a categorization (i.e. green, blue, yellow, red and black) of the industries based on the environmental performances (Yuan et al., 2008). Meso level concentrates on establishing and maintaining a network of eco-industrial parks; altogether they account for nearly half of China's manufacturing output (Mathews & Tan, 2016; McDowall et al., 2017). The concentrated production outlets in the industrial zone and parks makes it easier to monitor and implement CE technologies. For example, the Suzhou New District for example, houses around 4,000 businesses in a 52 square km area and one manufacturing plant produces printed circuit boards that uses copper recovered within the park (Mathews & Tan, 2016). Eco-city, eco-community, or eco-province are at the macro-level of CE implementation. The main difference between the eco-industrial park and the eco-city is while the former focuses mostly focuses on implementing CE in production processes, the later takes the consumption also in consideration (Yuan et al., 2008). As one of the first few demonstration city, the southernmost coastal city, Dalian, identifies four key resources (land, water, materials and energy) and three industrial sectors (agriculture, construction and the service sector including tourism) to focus its CE implementation (Geng et al., 2009). In the water infrastructure for example, the city plan to impose price on waste water treatment at the same time providing subsidies for using rainwater and desalinised sea water (Geng et al., 2009).

2.3.2 European model

Some sort of circularity in the form of waste reduction and prevention, existed in Europe since the mid-1970s; the waste hierarchy (i.e. 3R framework) was adopted as the principle waste management policy in the first EU waste framework directive 75/442/EEC (EC-JRC, 1975; Lazarevic, Buclet, & Brandt, 2010). Resource efficiency was the next, promoted as the flagship agenda in Europe 2020 strategy 'The Roadmap to a resource efficient Europe'

(COM/2011/0571, 2011). This was followed up by policy measures commonly known as Circular Economy package and then updated in 2015 with ‘Closing the loop - An EU action plan for the Circular Economy’ (table 2-4) (European Commission, 2015; McDowall et al., 2017).

Table 2-4: Summary of the EU 2015 action plan for CE in three key areas with milestones from Horizon 2020, adapted from Domenech & Bahn-Walkowiak (2019) and McDowall et al. (2017).

Areas	**Examples of specific policies Production**	**Milestones by 2020**
Production	Eco-design: proposal to adapt the existing eco-design work plan (under Europe’s Eco-Design Directive) to incorporate durability, reparability, and recyclability criteria Cleaner manufacturing: Research & Development funding, knowledge centers	Market and policy incentives to reward efficiency. Companies can measure and benchmark lifecycle resource efficiency Phase out Environmentally Harmful Subsidies (EHS) Shift taxation from labor to environmental taxation
Consumption	Proposed introduction of product labeling for durability Pricing: member states are “encouraged” to use pricing instruments. Consumer protection rules: e.g., guarantee periods Various proposed measures to promote “innovative consumption,” including collaborative consumption models based on leasing, lending, and sharing Adapting existing public procurement rules	Appropriate price signals and products and services environmental information. Minimum performance standards for products and services
Waste Management	New legislative proposals on waste and landfills, including new binding targets Proposed changes to extended produce responsibility rules to reward products that are designed for easier repair, remanufacture, or recycling Direct funding support for “laggard” regions by cohesion policy	Waste production is in absolute decline Recycling and reuse of waste streams Energy recovery only to non-recyclable materials Eradication of illegal waste shipments Full implementation of waste legislation Landfilling is phased out High quality recycling

In contrast to China, CE is perceived as a response to foster growth within the environmental constraints in a resource efficient way rather focusing concern on pollution (McDowall et al., 2017). CE is rather conceived as a way for Europe to have a competitive edge by cross cutting across the value chain with improved production; CE business models are expected to contribute a 3.9% GDP growth in EU by 2030 (Domenech & Bahn-Walkowiak, 2019; Ellen MacArthur Foundation, 2012). McDowall et al. (2017) undertook a quantitative text analysis on the policy documents on CE in EU and China; the result shows that while innovation is more frequently used in EU, pollution is used more in the Chinese discourse. Emphasis is also large on business models and consumption pattern but EU policies have almost nothing in regard of land use and scale in CE (McDowall et al., 2017). EU's CE action plan nonetheless includes a legislative action when it comes to waste directives (Bahn-Walkowiak, 2019). The legally binding targets for member states with penalties for noncompliance include 65% of municipal waste to be recycled by 2030; the target is 75% for packaging waste and waste ending up in landfill is 10% (Domenech & Bahn-Walkowiak, 2019).

3 Cities in Circular Economy

Cities are hubs of government, commerce, and transport, with large concentration of people living and working together, but the geographic limit of cities is hard to decide (United Nations, 2018). OECD-EC created a density matrix for harmonised understanding of cities in all of its' regions and identified 828 (greater) cities with an urban centre of at least 50,000 inhabitants in the Europe and 492 cities in Canada, Mexico, Japan, South Korea, and the USA (Dijkstra & Poleman, 2012). Although cities since long have been dominating the landscapes of human settlements, up until recently, more people lived in rural areas than in cities. In 2007, the urban population overtook for the first time and is expected to see a significant rise in the future (figure 3-1) (Ritchie & Roser, 2020). In 2018, around 55% of the world population lived in cities and by 2050, urban population is projected to rise up to 75% (Diez, 2011; United Nations, 2018). As the core of human settlements and the engines powering economic growth, cities are expected to be in the forefront of realising the circular strategies (Ellen MacArthur Foundation, 2020b). But the driving force behind cities necessity to adapt, is that in the present 'linear' system, cities consume almost 75% of natural resources and almost 50% of all wastes (Ellen MacArthur Foundation, 2020b). A study by Folke et al. (1997) on 29 largest cities in Baltic Europe shows that cities require at least 565 – 1,130 times larger functioning ecosystems (e.g. forest, agricultural, marine, etc.) than the area of the cities themselves for their resource consumption and waste assimilation (figure 3-2). Adding the prospect of climate change in the list of adversities, many cities are now turning to CE for guiding their paths towards sustainable futures (Prendeville et al., 2018).

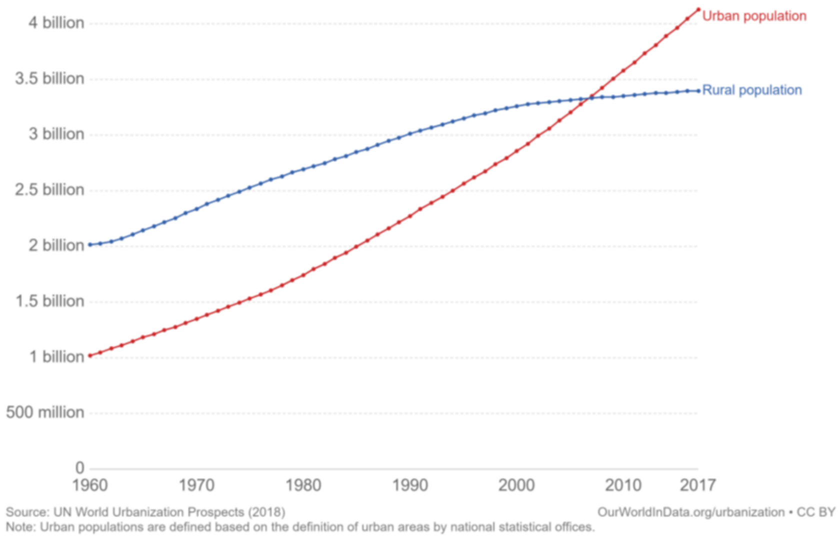
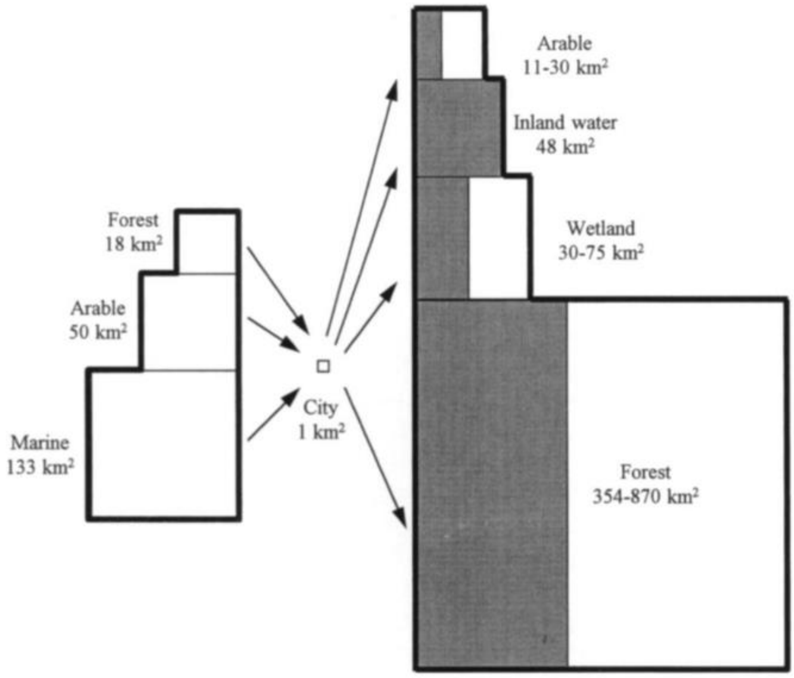


Figure 3-1: Worlds' urban and rural population comparison over time, retrieved from Ritchie & Roser (2020).

In this chapter, prospect of CE in cities has been explored in literature on two levels; the macro level where the city has been regarded as an entity to employ CE strategies, and the micro level where different essential commodities (e.g. food, transport, etc.) has been explored separately.



Left: Ecosystem appropriation for natural resources production.

Right: Ecosystem appropriation for waste assimilation

* shaded area = low-range estimate

Figure 3-2: The ecological footprint of the 29 largest cities in the Baltic region of Europe; from Folke et al. (1997).

3.1 Macro level – City as an entity of production and moving towards self sufficiency

CE is still in its early phase of application with its effectivity still waiting verification, ‘circular city’ ideas have already started to take shape to spatially integrate circularity (Marin & De Meulder, 2018). The ‘circular city’ or ‘circular city-region’ concepts can be associated with self-sustainable, regenerating city ideas explained in the New Urban Agenda adopted by United Nations in 2016 (Gravagnuolo et al., 2019; United Nations (Habitat III), 2017). The idea is similar to the pre-existing ideas of ‘smart city’, ‘eco city’, ‘aero-waste city’ but is less explored due to the novelty of the concept and often gets tagged along as part of overall sustainability agenda of the city rather than a standalone strategy on its own (Prendeville et al., 2018). Different strategies for cc adaptation

3.1.1 Knowledge development - Spatial circularity drivers’ framework

To structure research and practices on Circular City perspective, Marin & De Meulder (2018) proposes a framework building on the concept of urban metabolism. By analysing circular strategies applied in 4 case study cities, they proposed a framework for spatial circularity which:

- ‘is systemic: it aims to relate micro, meso and macro scales within an ideal situation of regenerating ecosystems;
- envisions how people relate to the ecosystems they inhabit as part of circularity; and,
- combines both technocratic and emancipatory approaches, drawing both from management and politics’ (figure 3-3) (Marin & De Meulder, 2018).

Marin & De Meulder (2018) concludes that 'circular city agenda' needs to be multi-dimensional and would require expert input from a diverse set of disciplines (e.g. industrial ecology, political ecology, ecological economics, etc.). From the analysis of the case studies in their research, Marin & De Meulder (2018) suggests that 'urban landscape design' as a discipline demonstrate the ability to capture various components of circularity on a city scale and has the capacity to act as a pivot in guiding the research on circular cities.

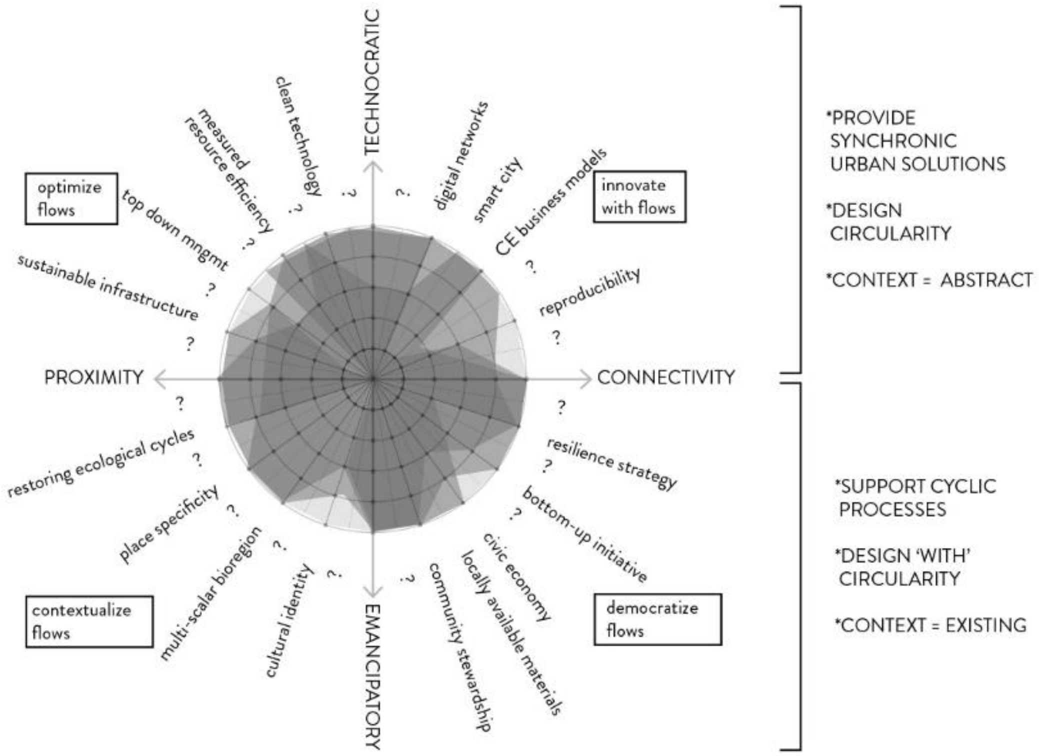


Figure 3-3: Spatial circularity drivers framework proposed by Marin & De Meulder (2018).

3.1.2 Stakeholder adaptation - Circular city project map

Prendeville et al. (2018) bases their 'circular city' framework in the ReSOLVE framework (section 2.2.3) that addresses both top-down institution driven changes and bottom-up social movements to integrate circular strategies at all levels (figure 3-4) (Ellen MacArthur Foundation, 2015). This framework was then used to analyse circular strategies adopted by six cities and the data then used to create a 'Circular city project map' (figure 3-5) (Prendeville et al., 2018).

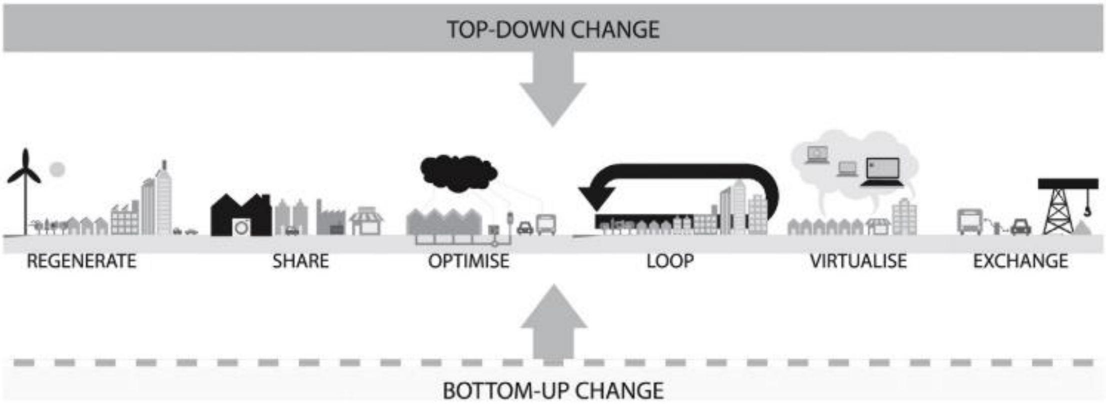


Figure 3-4: The circular city framework, from Prendeville et al. (2018).

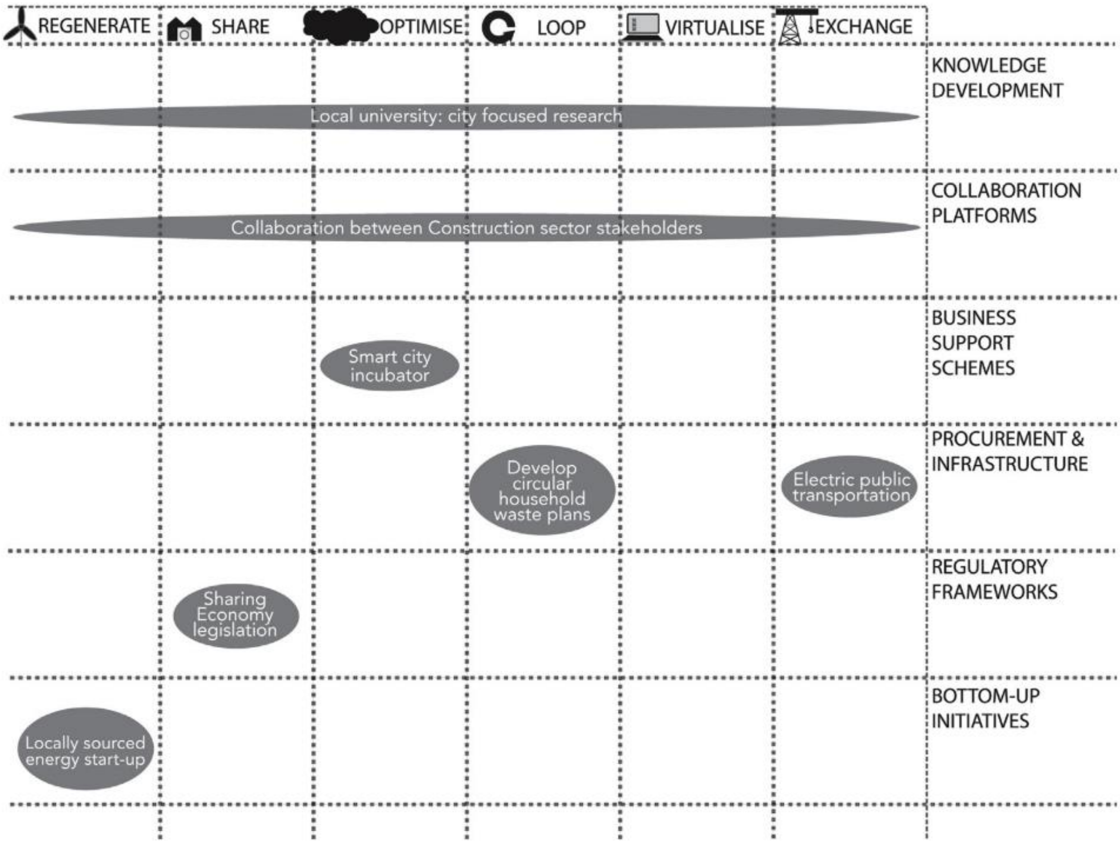


Figure 3-5: Circular city project map, from Prendeville et al. (2018).

Prendeville et al. (2018) additionally identifies 4 key stakeholder groups and elaborates their roles in realising the circular city strategies:

Businesses – Circular strategies adopted by case study cities are business-centric; repeatedly highlighted the need to 'drive' and 'grow' city's economy with innovative business models. Furthermore, city policymakers identify business-led innovation as a way of financing the overall circular agenda. However, progress on urban sustainability can be risked due to vested interest with overt reliance on powerful industrial partners.

Public sector – Civil servants are responsible for establishing circular initiatives and creating strategy documents at the city level. Local governments also create the link between the senior policy makers and general population dissipating awareness for circularity in both directions. But they are reluctant in taking financial incentives for new infrastructures as local authorities see themselves as ‘facilitators’ rather than ‘investors’. As each local government is usually in office for a limited amount of time until next election, councilors struggle to formulate long-term future visions.

Knowledge institutes – Defining and broadening the understanding of CE at city level is fundamental considering the current lack of knowledge in this field. Research institutes such as universities and consultancies with relevant expertise are expected to be key partners in knowledge development and contextualizing CE in cities in a bottom-up approach.

Citizens and communities – Citizen’s quality of life and wellbeing, and all the while the need for their behavioral change is considered in all the case studies in the research. Policy makers can learn from each individual case to better understand the complexity of citizen involvement. But there are inconsistencies in when it comes to reflecting the concern for citizen in policy making; business stakeholders and data-driven knowledge development have been consistently given higher priority. Citizen involvement is needed in CE to ensure participation in the governance in employing circular strategies in cities.

3.2 Micro level – City as a cluster of different services

3.2.1 Food

Food, especially in the urban setting, isn’t simply limited to cultivating crops anymore, agri-food industry is the ‘world’s largest industry’ consisting of over 1 billion people connected in a web of activities including processing, transporting, marketing, cooking, packaging, selling or delivering food (Jeffries, 2018; Murray, 2007). Current corporate agri-food system is a complex combination of activities and institutions operating simultaneously at multiple levels of scale (from global to local) and time (particularly with respect to the timing of outcomes); it is characterised by growing share of processed food in overall food sales and growing distance (both physical and virtual) between producers and consumers (Ledger, 2016). But this complex system has a very linear direction of flow as the final destination for most food products are the cities (figure 3-6) (Ellen MacArthur Foundation, 2018b).

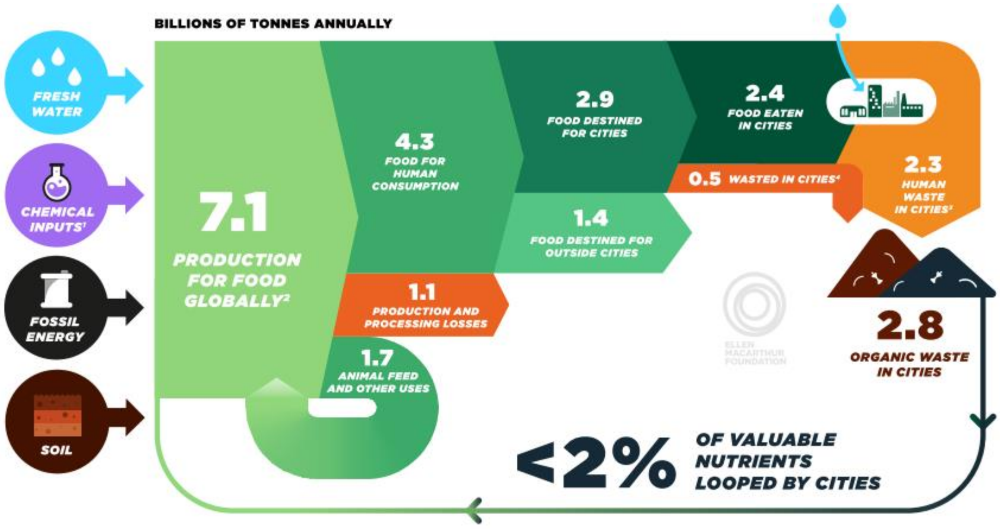


Figure 3-6: Present linear food system; from Ellen MacArthur Foundation (2018b).

While the entirety of the agri-food system is wasteful, waste occurs mostly in the primary stage in the developing countries but in the developed countries, wastages of consumption stage food products are often over 40% (Jurgilevich et al., 2016; Stuart, 2009). The waste seems even more unacceptable considering 821 million people in the world, one in every nine, goes to bed hungry every night (WFP, 2019). Furthermore, less than 2% of the biowaste created in cities is recycled (figure 3-6) (Ellen MacArthur Foundation, 2018b). Even with ensured food access, there are many associated health issues such as nutrition deficiency and increasing obesity (cite). Food production also results in various environmental impacts such as contributing to 19 – 29% of total anthropogenic greenhouse gas emissions (Vermeulen et al., 2012). Ellen MacArthur Foundation (2018b) explains that for every one dollar spent on food, the world spend two dollars on costs associated with the negative impacts for health (e.g. obesity), environment, and economy. The current food system has a high potential to implement a CE perspective regarding cutting back waste, reducing the environmental impact, and ensuring better nutritional quality (Borrello et al., 2016; Ellen MacArthur Foundation, 2018b; Jurgilevich et al., 2016).

In the report 'Cities and Circular Economy for food', Ellen MacArthur Foundation proposes three ambitions to create a vision for 'food system fit for the future' to counter the problems of the existing system: source food grown regeneratively and locally when appropriate, make the most of food, and design and market healthier food products (figure 3-7). Jurgilevich et al. (2016) proposes a similar circular food system including three interconnected stages: food production, food consumption, and food surplus and waste management (figure 3-8). The three aspects of CE for food system is discussed followingly.

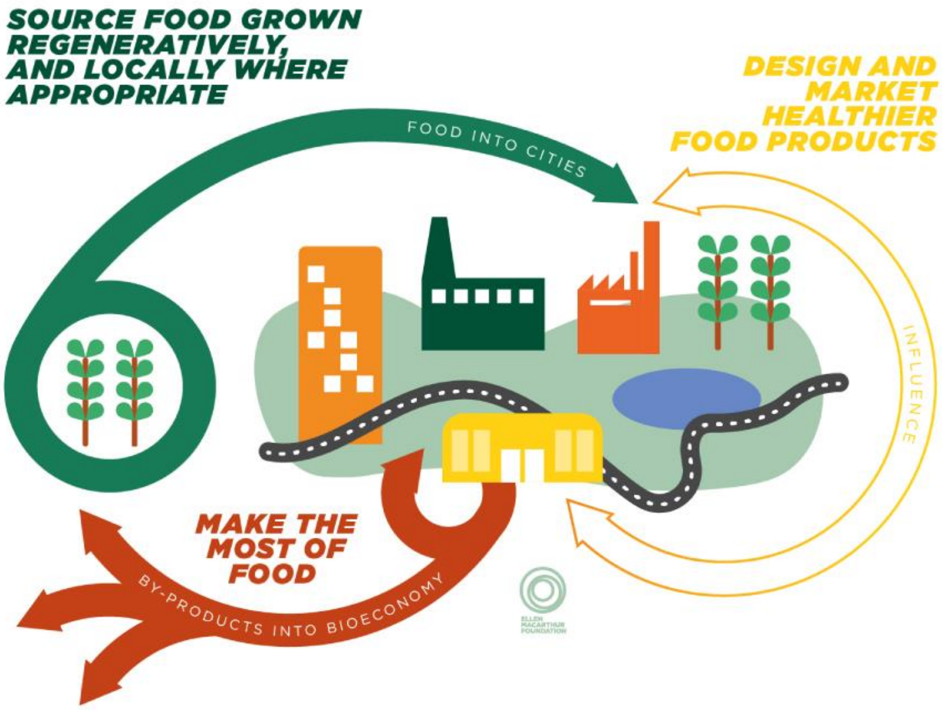


Figure 3-7: Food system fit for the future; from Ellen MacArthur Foundation (2018b).

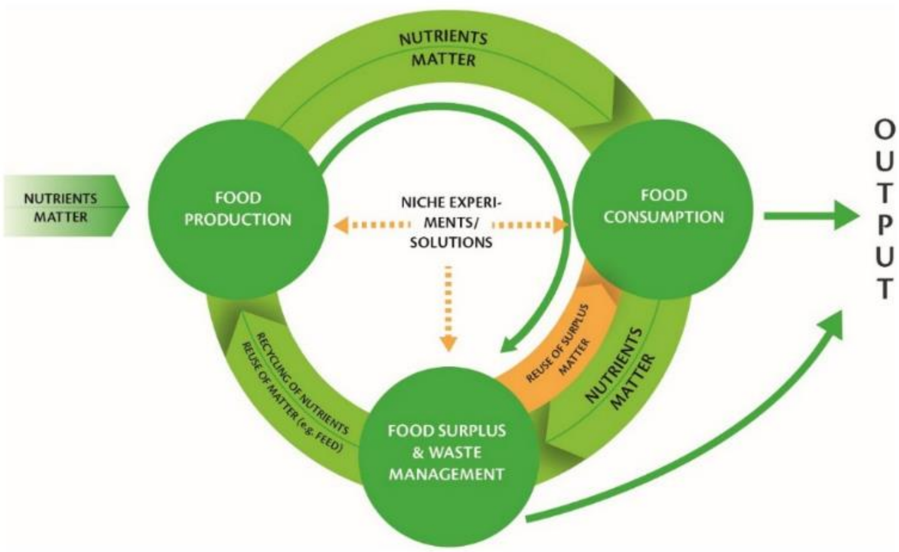


Figure 3-8: Three stages of the food system in a CE; from Jurgilevich et al. (2016).

3.2.1.1 Locally grown - Urban Agriculture (UA)

With 7.6 billion in 2017, the world population is growing fast and the population within the cities is growing even faster (United Nations, 2017). In 2014, 30% of the global population lived in the urban areas and it is expected to rise up to 66% by 2030 (United Nations, 2014). The growth of the urban population simultaneously triggers a greater demand for food supply, variety and, convenience; and most of the food production takes places outside in the fast depopulating rural areas (FAO, 2017). Only a quarter of the total population in Europe is living in rural areas and the continuous shrinkage of the rural population is an important factor in arable land abandonment, which further highlights urban food security issues: the EU region is predicted to lose another 2.5 million ha by 2030 (Bučienė, 2003; European Commission, 2017; United Nations, 2014). Urban Agriculture (UA) has long been advocated to tackle this specific challenge as well as a slew of related sustainability concerns: public health, healthy food access, green space, air and water quality, economic development and community engagement (Ackerman, 2012).

Although most of the food crop production takes place outside of city limits, agriculture, particularly horticulture maintained a niche within the urban areas and in some cities like Havana (Cuba), UA is the main source agriculture produce (Hamilton et al., 2014). Due to the current complexity of the food system, definitions and scope of UA can be very broad and diverse. The concern for this report is limited to small-scale cultivation of vegetables grown for self-consumption, the predominated form of UA, in urban and peri-urban areas (Hamilton et al., 2014; Zezza & Tasciotti, 2010). UA is practiced by about 800 million people around the world and most urban farmers grow food largely for self-consumption (FAO, 2019; Mougeot, 1999). UA varies largely in size, intensity and practice; from one's personal vegetable patch in the backyard to the large allotment garden with thousands of plots under city administration, all fall within the boundary of UA. Below, the motivation and practices of UA has been elaborated from the perspective of the developed and developing world; the information is largely derived from the review papers on these topics respectively by Mok et al. (2014) and Hamilton et al. (2014).

Motivation for engaging in UA:

Motivations for and practices of UA is here elaborated from the perspective of the developed and developing world based on information mainly derived from two review papers by Mok et al. (2014) and Hamilton et al. (2014).

In north America, Europe, and in Australia, the contemporary practice of UA has been initiated during a time of crisis, more specifically during the World Wars and the great depression (Mok et al., 2014). The war garden movement during the World War 1 and the relief garden movement during the great depression fueled the return of the UA practices in the USA (Bassett, 1981; Mok et al., 2014). Similarly, the 'Dig for victory' campaign in the UK and the 'Grow you own' campaign in Australia were introduced and supported by the respective governments in an attempt to increase food self-sufficiency during the World War 2 (Crouch & Ward, 1997; Gaynor, 2006; Mok et al., 2014). In Japan, by contrast, agricultural production was integral in the city fabric; up to 40% of urban land was designated for agricultural production in Tokyo in the 1800s (Mok et al., 2014; Yokohari et al., 2010).

Growing environmental awareness of the late 1960s and early 1970s, and more recently, mainstream publications (e.g. 'Omnivore's dilemma' by Michael Pollan) and media (e.g. Food, Inc documentary by Robert Kenner) have been driving the reintroduction of alternative production methods in the US as opposed to industrial agricultural systems (Bassett, 1981; Hynes & Howe, 2004; Mok et al., 2014; Pollan, 2006; Press & Arnould, 2011). The environmental movement in the US also inspired similar awareness across the globe; Mollison & Holmgren's book published in 1978 'Permaculture 1: A Perennial Agriculture system for human settlements' was published in 1978 started the permaculture movement which played and influential role in the insurgence of community gardens in Australia (Gaynor, 2006; Mok et al., 2014; Mollison & Holmgren, 1987). Japan, which depends on import to support a staggering 60% of their food consumption, has been trying to promote regional agriculture with campaigns such as 'Chisan-chiso' (locally produced and locally consumed) to create local awareness to support local farmers (MHLW, 2019; Mok et al., 2014; Yokohari et al., 2010).

Most cities in developing countries host a large number of migrating rural population that suffers from poverty and lacks the purchasing power to access food at regular price point (Orsini et al., 2013). The constant rural to urban migration creates a strain on the urban resources (Hamilton et al., 2014; Zezza & Tasciotti, 2010). To support the demand of such population coupled with the inadequacy of infrastructure needed to maintain a stable flow of produce to the cities from the rural areas, several types of agricultural systems developed in and around the urban periphery largely focus on providing fresh vegetables, dairy, and poultry (Drescher, 2004; Orsini et al., 2013). UA is also often a source of income as most practices are for commercial purpose (Hamilton et al., 2014; Zezza & Tasciotti, 2010). Even though the UA practices are widespread, in Indonesia for example, UA is treated as a temporary use of land responding to the need of present time (Hamilton et al., 2014).

For countries like Cuba, UA became a necessity due to their socio-economic situation. Cuba was highly dependent on the USSR for their resource import such as food, oil, and transport etc., but the supply gradually decreased to nothing in the 1990s and with trade embargo in place by the US, Cuba was not able to diversify their import options (Hamilton et al., 2014; Mesa-Lago, 1993; Pastor & Zimbalist, 2008; Rosset & Benjamin, 1994). The development of UA, supported by several state agencies, became widespread in Cuba; nearly 12% of the urban land in Havana is dedicated to UA (Cruz & Sánchez Medina, 2003; Orsini et al., 2013). UA benefits from strong governmental support throughout the Latin America at different level of jurisdictions and via different well established grassroot institutes (Hamilton et al., 2014).

Different forms of UA:

UA in North America can be divided largely into three categories according to their scale; small commercial farms and community supported agriculture (CSA), community gardens, and backyard gardens (Brown & Carter, 2003; Mok et al., 2014). Smallest in scale are the backyard gardens and these are comprising of food crop producing activities in the vicinity of one's home including rooftops and balconies (Brown & Carter, 2003; Mok et al., 2014). The United States Department of Agriculture (USDA) defines small farms as farms that generate less than USD 250,000 in yearly gross sales and CSA practices consisting of 'a community of individuals who pledge support to a farm operation so that the farmland becomes, either legally or spiritually, the community's farm, with the growers and consumers providing mutual support and sharing the risks and benefits of food production' (Brown & Carter, 2003; Mok et al., 2014; USDA, 2020). Community gardens can be compared to what known in the UK and Europe as allotments (Mok et al., 2014). These are large areas owned by municipalities, institutions, or groups and are divided into small subplots that can be rented out to individuals, groups, or communities (Kortright & Wakefield, 2011; Mok et al., 2014). The flexibility of the ownership and size allows the community garden to be developed in a variety of forms; among the examples are neighbourhood gardens, public housing gardens, school gardens, etc. (Kortright & Wakefield, 2011; Mok et al., 2014).

Figure 3-9: Examples of different types of UA: a. Community garden in Toledo, Ohio, b. Allotment garden in Salinas, California, c. Private garden in Toledo, Ohio, d. Easement garden in Melbourne, Australia, e. Rooftop garden in New York City, f. Urban orchard in San Jose, California. Photos courtesy of P. Bichier (a, b, f), P. Ross (c), G. Lokic (d), and K. McGuire (e); from Lin et al. (2015).

In UK and Europe at large, community garden refers to a gardening plot maintained by a community or a group and these, as well as city farms, are commonly used for keeping live stocks (Garnett, 1999; Mok et al., 2014). Allotments are the dominant form of UA in the UK and can, based on their ownership and legal protection, be divided into three types: statutory allotments, temporary allotments and private allotments (London Assembly, 2010; Mok et al., 2014). Statutory allotments are the most commonplace where the borough land is appropriated by a city council for the specific use of gardening and enjoys the most legal protection when it comes to maintaining the land-use for UA (London Assembly, 2010; Mok et al., 2014). Temporary allotments are hosted by councils and private allotments, as the name suggests, have private ownership, and both types share similar legal status of less prominent legal support (London Assembly, 2010; Mok et al., 2014).

Various types of UA practices exist in the developing world, the practices in sub-Saharan Africa is categorized by Abdulkadir et al. (2012) based on the combination of need of the farmers (e.g. commercial, semi-commercial, and subsistence) and produce type (e.g. field crop, vegetable gardening, and livestock). Cuba's state supported UA practices can be grouped according to four different production method: patios, parcelas, huertas intensivas, and organopónicos (Hamilton et al., 2014; Koont, 2011). Patios are basic home gardens and can be compared to that of backyard gardens of the US (Hamilton et al., 2014; Koont, 2011). Parcelas are parcels of unused land given to individuals for cultivation purposes (Hamilton et al., 2014; Koont, 2011). Huertas intensivas and organopónicos are raised bed extensive UA practices and differ in that the former only uses earth mound beds and the later has the mound fortified with walls (Hamilton et al., 2014; Koont, 2011). There are also many other informal UA practices such as fruit orchards and trees by the roadsides; the 'edible street' in Bangkok (Thailand) have many different types of fruit trees (tamarind, mango, jack- fruit) which are free to the public and are often preferred by the inhabitants for their freshness and safety (Hamilton et al., 2014; Suteethorn, 2009).

Technologies in UA:

UA practices, until very recently, remained simple in method and followed traditional small-scale farming techniques available and suitable in the region, such as raised beds, green houses, roof top practices (Hamilton et al., 2014; Mok et al., 2014). Their increasing popularity in recent times, however, has seen a surge of different technologies to increase the efficiency and output. Vertical farming, also known as sky farming, is gaining traction in the US and the developed world and bases its concept on creating an efficient farming system focusing on the crop rather than the natural environment (Mok et al., 2014). There are many technologies and variations available for vertical farming, but the common concept revolves around growing crops in vertically stacked layers often in an artificially controlled environment which often is free of soil (e.g. hydroponics) (Birkby, 2016).

Goldstein et al. (2016) proposes a classification of UA based on two criteria: conditioning of the growing spaces and level of integration with building. Space conditioning refers to the degree of interaction between the UA practice and the ambient environment (i.e. presence of external control over the growing space (Goldstein et al., 2016). Building integration refers to how the practice is physically embedded to a built space (Goldstein et al., 2016). The four categories proposed by Goldstein et al. (2016) with example is presented followingly:

(i) Ground-based-non-conditioned – Example: allotments,
(ii) Ground-based-conditioned – Example: Greenhouses,
(iii) Building-integrated-non-conditioned – Example: Rooftop gardens,
(iv) Building-integrated-conditioned – Example: Hydroponics.

3.2.1.2 Food processing

The complex agri-food system can be divided in to three sub-system based on the primary form of activity; farming, manufacturing and consuming (FoodDrinkEurope, 2016) (see figure 3-9). CE activities can take place simultaneously in different subsystems to achieve separate CE targets.

Preventing and reducing food loss: Preventing or reducing food loss is vital in CE implementation and there are various incentives addressing this issue already in place across the agri-food system. A lot of the food waste is due to superficial reason such as being not aesthetically pleasing; up to two fifth of produced fruits and vegetables goes to waste because they don't meet the standard appearance of the food retailers (The Guardian, 2013). 'Food forward' is an organization that collects the unsold farm produce and donates them to charity and 'Imperfect food' sells produce that failed to make the grade at a lesser price (Food Forward, 2019; ImperfectProduce, 2019; Jensen, 2017). Provalor of the Netherlands on the other hand built an entire product system based on rejected produce, it collects rejected fruits and vegetables from farmers and manufacturers to make juice and sells the pulp byproduct to a sauce producer (FoodDrinkEurope, 2016). To prevent imperfect produce altogether, selective breeding practices are also being implemented (FoodDrinkEurope, 2016). Shelf life and food mile are another two main reasons food going to waste. Movements like 'farm to table' and smart agriculture has long been established as processes to reduce food mile and thus contributing in reduction of food waste (Janzer, 2018; Jurgilevich et al., 2016). As well as consumer awareness and efficiency in storing foods with apps like Foodkeeper, products like banana bag and ethylene absorption disc also help increase the produce life span (Robison, 2013; USDA, 2015).

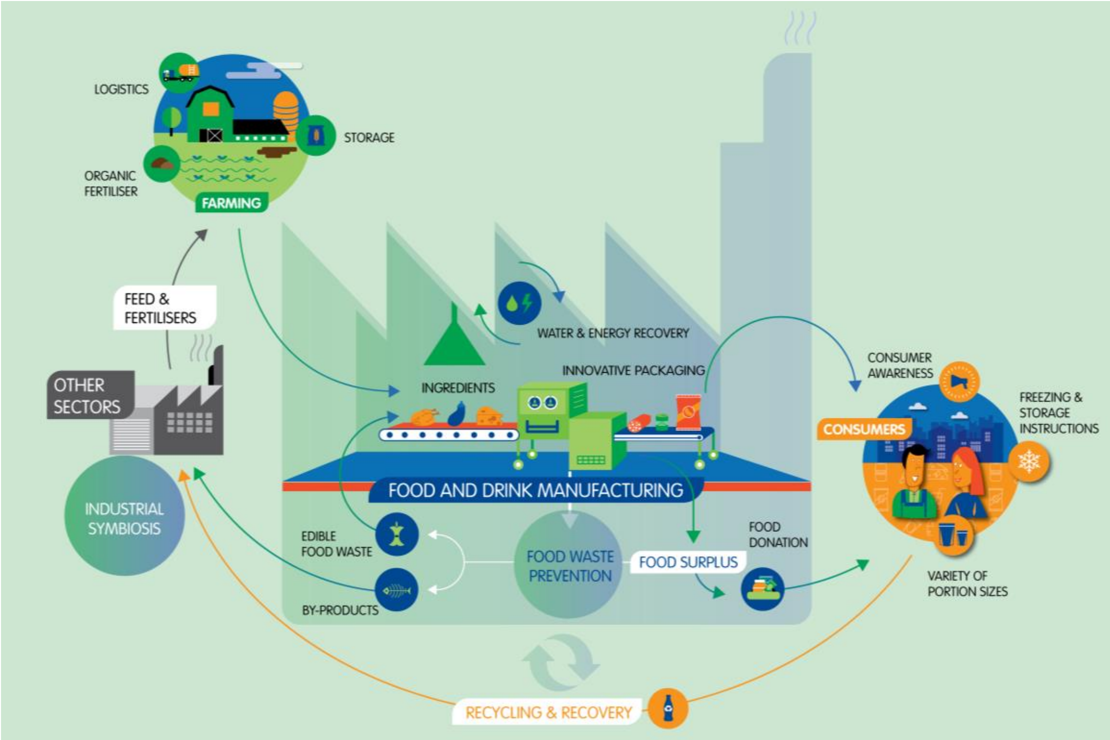


Figure 3-10: Application of CE across the food value chain, from FoodDrinkEurope (2016).

Generating less waste during processing: Manufacturers can also optimize their production processes to generate less and less waste; Pepsico diverted 95% of their waste away from landfills through reuse, recycle, and waste-to-energy in 2017 and is working to achieve zero landfill waste in near future (Pepsico, 2017). Reusing or repurposing byproducts is another way of tackle waste production in manufacturing. Dutch bakery ingredient producer Sonneveld developed a process that allows bread that is unsuitable for sale to be repurposed as sourdough bread and the Evian factory in France turns agricultural waste into fertilizer (Danone Down To Earth, 2017; Sonneveld, 2019) (figure 3-10). Another common use of byproducts and waste is as fuel; one Swedish factory of Ben & Jerry's ice cream uses the fatty acid byproduct as boiler fuel and, Croatian meat processors PIK and Belje turns some of their waste to energy at biogas plant (FoodDrinkEurope, 2016).

Increasing resource efficiency: Resource efficiency is important for manufactures not only for CE implementation and environmental degradation but also for the positive impact on their profit margin. US EPA developed the Recyclable Content (ReCon) tool that tracks life-cycle GHG emissions of purchasing/manufacturing and the output in return helps manufacturers such as Pepsico to create a more efficient system (Pepsico, 2017; US EPA, 2020b). About 90% of the steam required for the Mars factory in Haguenau is generated by an incineration factory and Kellogg factories in UK is experimenting with recovering heat from exhaust resulting in a reduction of over 3,700 MWh (FoodDrinkEurope, 2016).

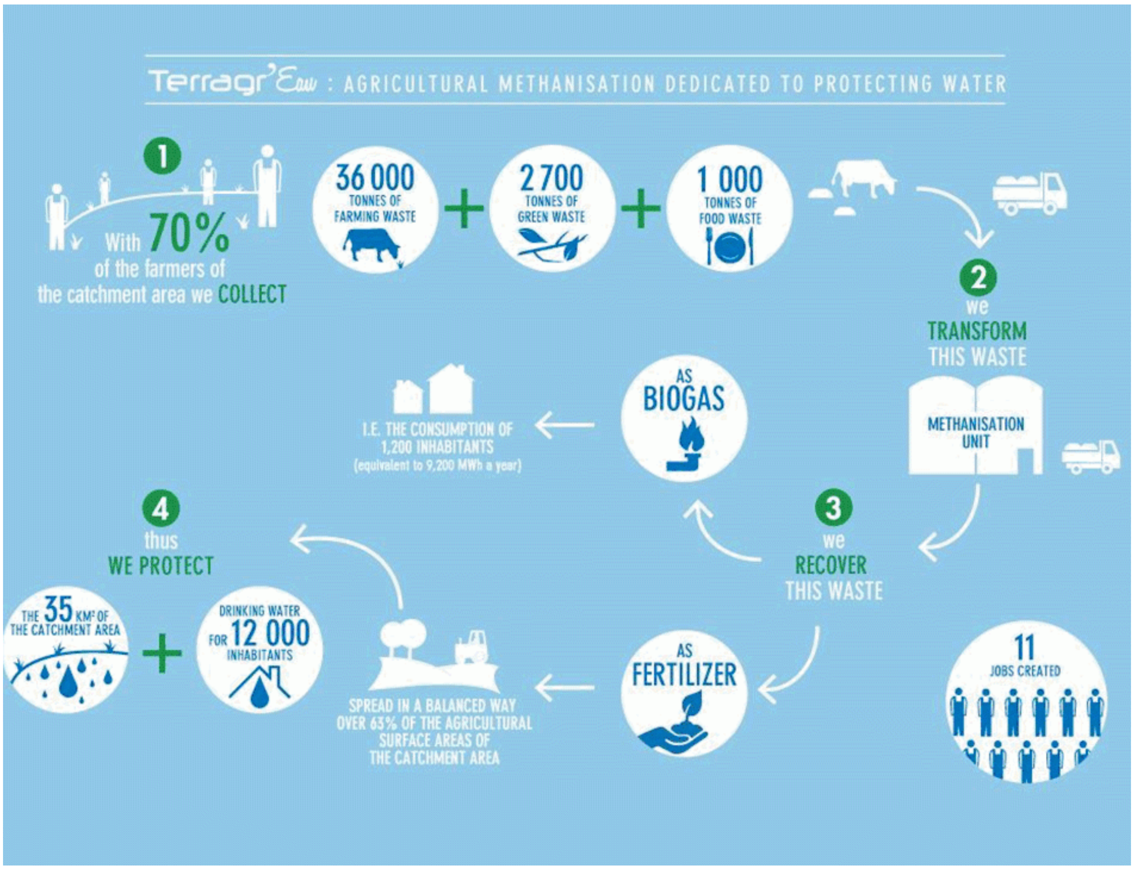


Figure 3-11: Danone-Evian's strategy for value creation from waste, from Ellen MacArthur Foundation (2020a).

Reducing packaging waste: Another wasted resource is food packaging: food packaging accounts for almost two-thirds of the total packaging waste by volume (K. Marsh & Bugusu, 2007). Berlin based supermarket 'Original Unverpackt' markets as many as 600 product including drinks and grains without packaging and shoppers pay by weight and volume; at least one such shop that allows reusable containers can be found in every major cities in Europe and USA using the 'zerowastehome' app (Brustscher, 2019). When packaging is an integral part of the product, there's still scope of resourcing and using in more sustainable way. Coca-Cola has distributed more than 30 billion 'plantbottles' made up to 30% plant-based materials in 40 countries since 2009 (Anderson, 2015). Unilever in Brussels promotes reuse of transport packaging by using weaker postage tape and PIK in Croatia switches to recyclable plastic packaging from previous one time cardboard packaging (FoodDrinkEurope, 2016).

Simple consumption change can bring in larger change as it would drive to change a combination of farming and manufacturing activities. Activities like 'Vegetarian day' in Helsinki where schools provide vegetarian lunch once a week, 'less but better meat' movement that promotes consumption of meat of higher price sourced from organic and free-range farms to lessen the impact of food industry on the environment (Jurgilevich et al., 2016).

3.2.1.3 Challenges of CE implementation

Application of the concept is not expected to be easy; seven challenges for transitioning into a bio-based CE in the supply chain for bread has been identified by Borrello et al. (2016):

i. **Regulatory limitations**
When there is a necessity for new, or improvement of traditional measures, current legislation is not enough to support the process.

ii. **Reverse cycle logistic management**
It is necessary to create closed loops unlike traditional linear one to implement CE; designing, managing and optimizing logistic for the reverse loops is time and cost consuming.

iii. **Geographic dispersion of enterprises**
Different stakeholders for one product in the current agri-food system can be dispersed across the globe. It is difficult to cut back on the transportation when local sources are not present which entails a significant input in the total carbon footprint of the product.

iv. **System boundaries and leakages of materials**
The agri-food supply chain is complex, and it is hard to define a neat system boundary to maintain smooth material flow and ensure no leakage of materials is taking place.

v. **Acceptance among consumers**
Changing the consumption and dietary habits of the consumers is a challenge; especially in the developed countries where the consumers can afford to waste food.

vi. **Technology development and diffusion**
Implementation of CE model would require technical development and it needs to happen across the entire supply chain for the system to function.

vii. **Uncertainty of investments and incentives**
Firms in the agri-food industry or any other sector in general find it difficult to invest on the circular business model which is new and thus profit is uncertain. High failure rate of the new measures (46%) is also one of the hindrances.

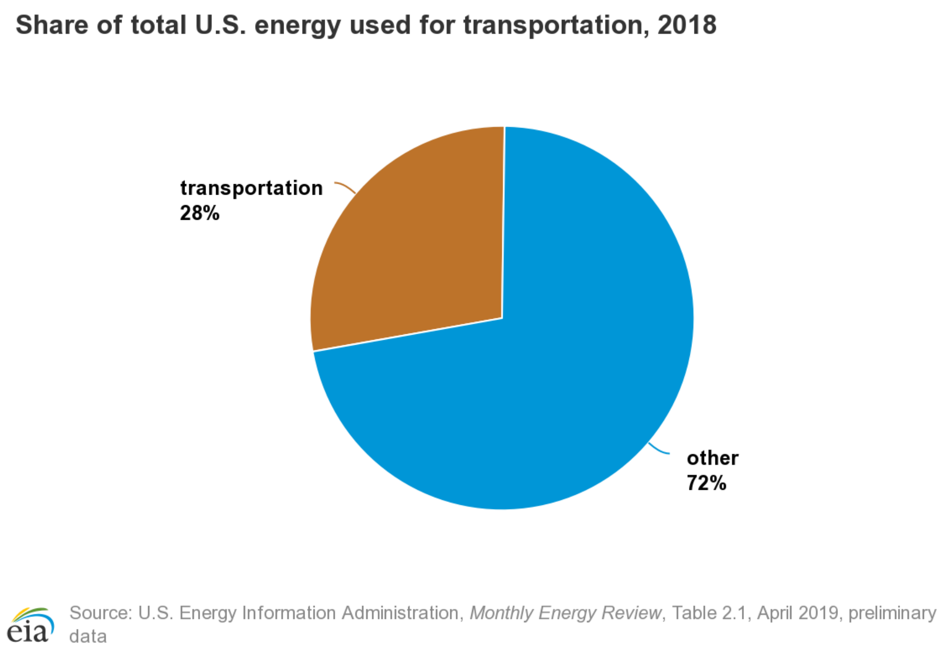
3.2.2 Transportation

Cities are intricately linked with transportation that defines and modifies the process of urbanization (Antrop, 2004). Railroads ensuring mass mobility was critical for the city development in 18th century and after the second world war, the development of private automobiles dominated the shaping of urban morphology giving rise to the 'Automotive cities' highlighting the citizens' dependence on personal vehicles (Antrop, 2004; Norton, 2008). The mobility of the inhabitants of the cities is only one aspect as the system also includes transport of materials and services in and out of the urban areas (Ellen MacArthur Foundation, 2019). Thus, a large part of the sustainability discussion within the urban periphery is regarding the transportation sector as it is the sector where greenhouse gas (GHG) emission has increased by 26% when the overall GHG emission in Europe has lowered 1.6% by 1990 to 2005 (EEA, 2007; Silvestrini et al., 2010). The sector comes under even more scrutiny as it is expected to grow further; between 2000 and 2050, 140%, 75%, and 70% in aviation, freight transport, and private motor transport, respectively (IEA, 2019).

The transportation sector has been experimenting and employing various circular strategies over time with some globally renounced and commercially successful initiatives from online ride sharing platforms to biofuels as alternative of fossil fuels (Gao et al., 2014). The strategies are divided in two parts, fuel and vehicles, and discussed briefly in the following.

3.2.2.1 Fuel

Transportation is a major source of energy consumption and current transportation system is heavily depended on a singular fossil fuel, petroleum (Figure 3-11) (US EIA, 2019). The impending transition to more renewable source of fuel is critical for this sector but at the same time, previous oil crises has helped the sector to prepare for the challenges (Samuels et al., 1982). The fuel crisis of the 70s had sparked the use of ethanol as an alternate fuel long before the concern over the sustainability of fossil fuel took place (Hansen et al., 2005). But the stabilised flow of cheap oil in the market for the past couple of decades has slowed the renewable fuel penetration in transportation sector (Marlair et al., 2009). The current drive for renewable energy in transportation sector is thus shaped by legislative measures to fulfil SDG criteria such as the legally binding Renewable Energy Directive (RED; 2003/30/EC) in EU that requires all member states to achieve 32% share of renewable energy for all land transport by 2030 (European Union, 2018).



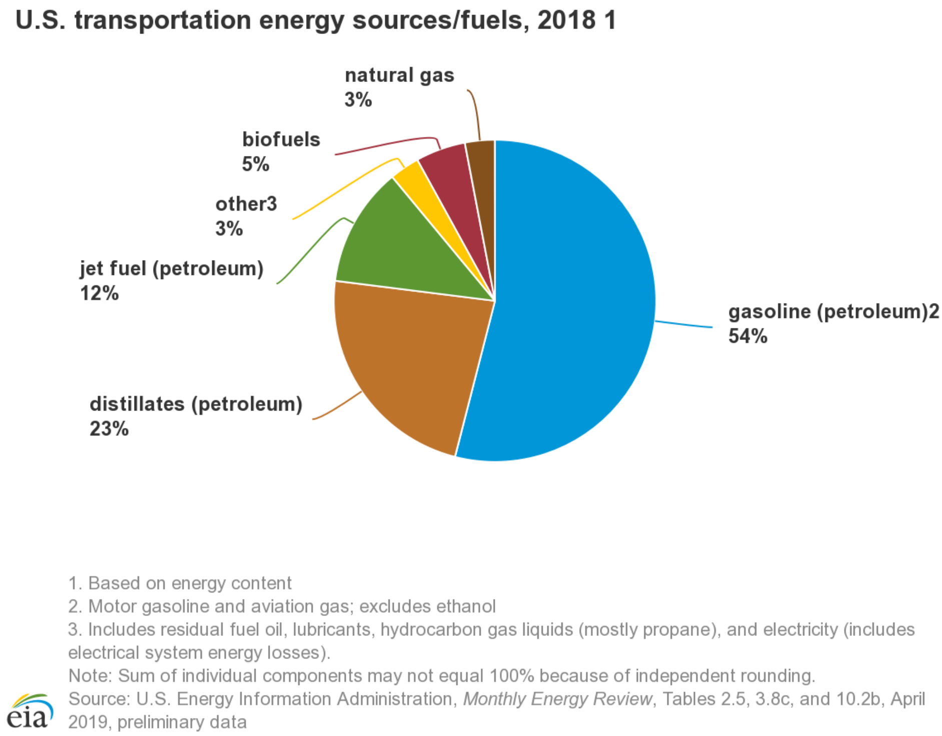


Figure 3-12: Energy demand and diversification of energy resources of transportation sector (US EIA, 2019).

Biofuel

Biofuels are hydrocarbon fuels that are derived from organic matter in a short period of time unlike fossil fuels, which takes millions of years to produce (Biofuel.org.uk, 2019). The more conventional biofuels such as ethanol has been popularised as a blend with gasoline in the USA during the fuel crisis of the 1970s and 10% blend known as E10 is used in midwestern states of the USA and 22% blend is commonly used in Brazil (Deenanath et al., 2012; Hansen et al., 2005). Even though pure ethanol (95% ethanol and 5% water) in itself is an excellent fuel but the more common application has been using it as blend with gasoline (Prasad et al., 2006). The first generation of biofuels used edible food crops as feed stocks (i.e. energy crops) that generated the 'fuel vs. food' conflict which promoted the second generation that uses waste stream biomass to produce fuels (Marlair et al., 2009). Currently research has been ongoing on the third generation of biofuels that would be produced entirely from algal biomass (Lee & Lavoie, 2013). A comparison between three generation of biofuels and consecutive fossil fuels is presented in table 3-1.

Biorefineries are required to process the biomass feedstock into usable biofuels. While the first generation of biofuels would require the refineries to be placed at the centre of farming communities as it depended on harvested crops as feedstock but the second generation using food waste and unrecyclable papers allows the refineries to be positioned in the urban or sub-urban areas (Jacquet et al., 2015). While the EU biofuel directive is driving the member nations to adopt measures (i.e. tax exemption) to promote biofuel, major European cities like Berlin and London to voluntarily experimenting with innovative pilot projects to incorporate biofuel in city traffic (Silvestrini et al., 2010).

Electricity

Among the alternatives of fossil fuels in transport, electricity has seen the most advancement with recent times with electric vehicles (EV) that uses electricity to power the vehicles. Electromobility is a road transport system based on vehicles that are propelled by electricity produced using different energy supply systems (Sandén & Wallgren, 2017). The possibility of generating electricity fully from renewable sources and their ability in lowering CO2 emission drastically makes it a lucrative option; the market share of EV is growing rapidly with almost 5 million EVs on the road almost double that of year before (IEA, 2019). The fuelling technology with electricity also has come a long way and at present charging outlets in gas stations or carparks are getting more and more commonplace but there are still lack of charging infrastructure to support the rapidly increasing demands (Engel et al., 2018). The current EV vehicles, technologies and sources are compared in figure 3-12.

Apart from alternating for biofuels there are also hybrid vehicles that can use both electricity and biodiesel; the Volvo group has been experimenting with a plug-in hybrid type as public transport buses in Gothenburg (Sweden) which has shown to reduce the greenhouse gas emission (GHG) by 75% (Sinclair, 2013).

Table 3-1: Comparison among different generations of biofuels and with respective fossil fuels.

Types of biofuel	First Generation (Marlair et al., 2009)		Second generation (Marlair et al., 2009)		Third generation		Differences with respective fossil fuel (Biofuel.org.uk, 2019)
	Biomass feedstock	Production process	Biomass feedstock	Production process	Biomass feedstock	Production process	
Bioethanol	Sugar beet, sugar cane, grains (e.g. corn, wheat, barley), potatoes etc.	Hydrolysis and fermentation.	Lignocellulosic biomass (e.g. wheat straw, corn stroves, etc.).	Advanced chemical and/or enzymatic hydrolysis and fermentation.	Algal biomass (Jambo et al., 2016).	Hydrolysis, fermentation, distillation (Jambo et al., 2016).	Ethanol compared to gasoline/ethane - has half the energy per mass of gasoline. - burns cleaner than gasoline. - produces less carbon monoxide but more ozone. - requires engine modification.
Biodiesel	Oil crops (e.g. rapeseed, sunflower seed, etc.).	Hydrotreatment.	Algal biomass (Jambo et al., 2016).			Transesterification (Behera et al., 2015).	Biodiesel compared to regular diesel -has only slightly less energy. -burns cleaner producing less particulate and fewer sulphur compounds. -more corrosive to engine parts.
Biogas	(Wet) biomass.	Digestion and refining.	Lignocellulosic biomass.	Gasification and synthesis or biological process.	Algal biomass (Jambo et al., 2016).	Anaerobic digestion (Behera et al., 2015).	Biogas compared to natural gas -has slightly less energy; 1 Nm3 biogas has 9.67 kWh energy whereas 1 Nm3 natural gas has 11 kWh (Eriksson, 2010).
Biobutanol (Bio-ETBE; ETBE = Ethyl tert-butyl ether)	Bioethanol (etherified).	Chemical synthesis.	Lignocellulosic biomass (Mahapatra & Kumar, 2017).	Anaerobic fermentation – ABE process (Acetone-Butanol-Ethanol) (Mahapatra & Kumar, 2017).	Algal biomass - Microalgae-based carbohydrates (Wang et al., 2017).	Biomass pre - treatment and Anaerobic fermentation (Wang et al., 2017).	Biobutanol compared to gasoline -has slightly less energy -can run in any car that uses gasoline without the need for modification to engine components.
Syngas			Lignocellulosic biomass.	Biomass pre-treatment, gasification, gas shift and synthesis.	Algal biomass (Jambo et al., 2016).	Gasification and pyrolysis (Behera et al., 2015).	

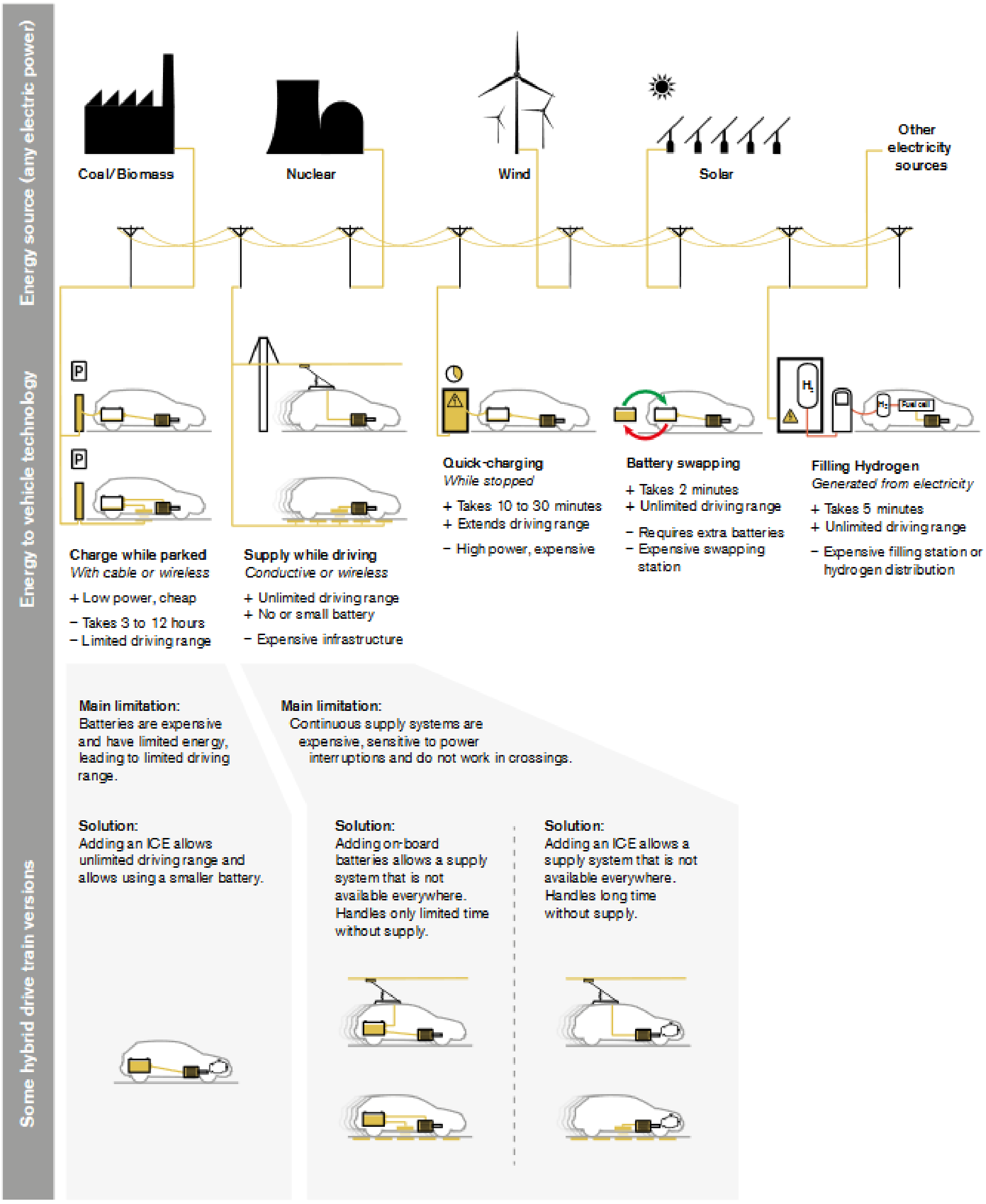


Figure 3-13:Examples of EV technologies and electricity sources; from Sandén & Wallgren (2017).

3.2.2.2 Vehicles

There are around 270 million light vehicles and 20 million heavy duty vehicles active in European Union alone (Saidani et al., 2018). The automotive industry is also the prime consumer of many finite resources such as lead; 60% of global lead production is used in cars and the reserve for that is expected to run out by 2030 (Ellen MacArthur Foundation, 2012). But the sale of cars is steadily increasing by 3% yearly on average and will be almost 1.5 billion cars worldwide by 2050 with a 50% rise of the total in 2012 threatening to increase the impact of the industry unless drastic changes are made(figure 3-13) (Gao et al., 2014). To address these challenges, Europe's automotive sector invests heavily in innovations to reduce the footprint, improving design and often, redesign, and manufacture efficiency (ACEA, 2019).

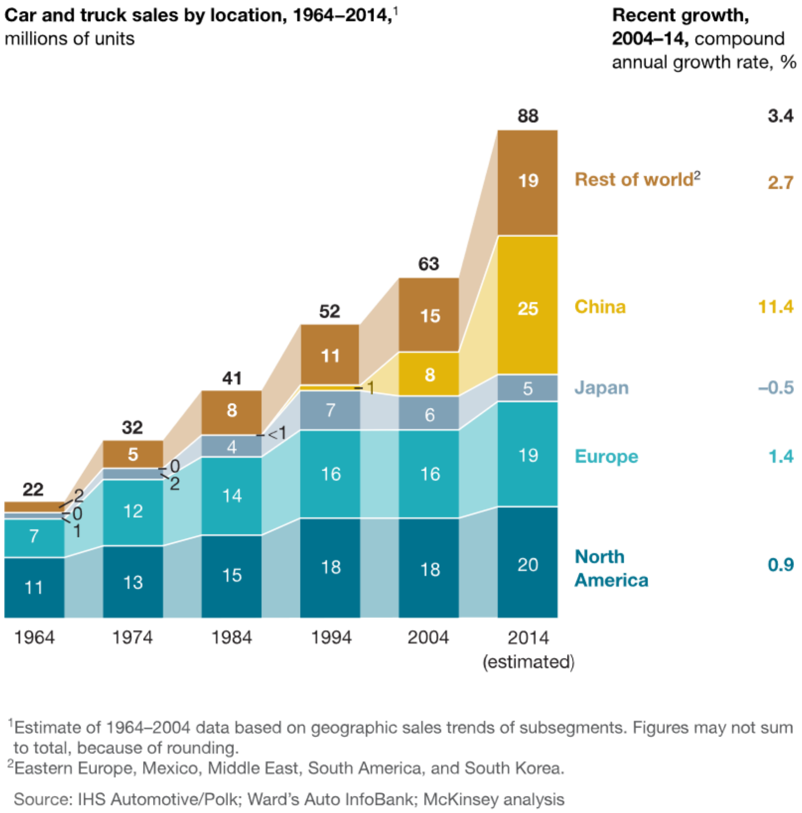


Figure 3-14: Global prospective of motor-vehicle sales, from Gao et al. (2014).

Manufacture efficiency

The industrial system has in general largely benefitted from the inventions in the automotive industry. Henry Ford's 'moving assembly line' developed in 1903 created the backbone of current industrial system (Ford, 2013). Using conveyor belt to run the production chain, Ford motors managed to produce Model T in one hour thirty minutes that would've taken twelve hours before (Ford, 2019). Later, Toyota employed a more effective lean manufacturing, a system that eliminates waste, of both time and resource, without reducing productivity, which is conceptually identical to the present day circular thinking (Sugimori et al., 1977). Created by Taichi Ohno in in the 1950s, then vice president of Toyota motors, 'Toyota Production System or TPS' has two main conceptual pillars (Sugimori et al., 1977; Toyota, 2019):

- Just-in-time – making what is needed, when its needed, and the amount needed; and
- Jidoka (autonomation with human touch) – replicating human processes in machine and perfecting it by eliminating errors over time with continuous improvement or Kaizen.

Toyota made their system available with the official publication in 1992 'Toyota Production System or TPS' (Toyota, 2019). From 1995 to 2004, Toyota took on average 30 fewer days in supply chain than General Motors due to their efficient production system (Cachon & Olivares, 2010). Japan overall is also the best case scenario when it comes to recycling car parts after end of life with less than 1% ending up in landfills whereas in Europe, the recovery rate is less than 85% with EU target being 95% (Despeisse et al., 2015).

To incorporate circular initiatives in the industry, auto manufacturers in Europe are presently employing remanufacturing for many of their parts are created by using a combination of reused, repaired and new parts reducing the energy consumption by 80% compared to new parts (ACEA, 2019). Since 1945, Volvo has employed a remanufacturing system where they bring back the undamaged parts in use that started out of necessity from WW2 material shortage (Volvo, 2019).

Material innovation
As well as increasing the efficiency of the production system, auto makers are also looking to diversify the materials with implementing renewable ones. More commonly, car makers are experimenting with bio-based plastics to replicate car parts. Following table 3-2 summarizes the practice of few auto makers to incorporate bio-based materials in the auto parts production.

Table 3-2: Bio-based materials used by automakers, information from Andresen et al. (2012).

Daimler (Mercedes Benz line)	
Bioplastics	The air filter system is made of 60% polyamide. Many bioplastic alternatives of current auto parts (e.g. accelerator pedal module, cogwheel, cooling fan, etc.) are also under trials in collaboration with German Federal Ministry of Education and Research.
Bio-based fibers and latex	Processed flax, hemp, and sisal is used for door cladding, seatbelt linings, and package shelves. Coconut fiber and natural rubber is used for seat bottoms, back cushion and head restrains.
Wood	Abaca tree is used for under-floor body panels.
Honda	
Bioplastics	Several Ford car models (Mustang, Expedition, focus, Escape, etc.) use soy-based plastic foam in the seat cushions and seat backs.
Bio-based fibers	Flax fiber reinforced linseed acrylate is used to make parts of the Mustang GT RTD body.
General Motors	
Bio-based fibers	Kenaf and flax mixture is used for making the package trays and door panel inserts in the Saturn L300 and Opel Vectra.
Mazda	
Bioplastics	Instrument panel and other interior fittings use bioplastics.
Bio-based fibers	Mazda developed a fabric made entirely out of bio-fibers to make seat covers and door trims for the model.
Honda	
Bio-based fibers	Honda has also developed plant-based fabric for its vehicle’s interiors (e.g. seat covers, headliners, floor mats).
Renault	
Bio-composites	For Renault Megane Trophy the BioConcept car, bio-composites are used to make several body parts (e.g. doors, fenders, engine hood, bumpers, etc.) as well as using biofuel to drive.

Vehicle longevity

Apart from shifting to renewable materials whenever possible, car makers have also been practising using durable materials for production to reduce the wear and tear during use and thus lengthening the vehicle life span (Ford, 2012). Japanese cars started the trend of fuel efficient long lasting cars to counter the American 'Diesel guzzlers' but more and more car companies have followed suite due to intense market competition, Hyundai and Kia offers a 100,000-mile/10-year warranties on their cars' powertrains (Ford, 2012). Extending cars' lifespan also has a positive environmental impact as it has been found to be a more effective way to reduce CO2 emissions rather than increasing the fuel efficiency (Kagawa et al., 2011).

Car mileage has long been the selling point of the Japanese car manufacturers, Toyota models rank top in the most car longevity lists (top five of this list by Martell (2018)). Car dealers and enthusiasts maintain communities such as 'The High mile club' to promote buyers to use the vehicle for a longer time period (The High Mile Club, 2019). Some car manufactures also integrate car longevity as promotion such as Volvo and Mercedes-Benz have a similar "High Mileage Award" program for car owners with 250,000, 500,000, 750,000, and 1 million km are awarded with a certificate and a radiator grille badge (Mercedes-Benz, 2019; Volvo Lastvagnar, 2019).

Recycling and refabricating

Recycling and refabricating, especially car parts, have been practiced by the car manufacturers since 1949 and when CE concept came to prominence, this served as a tailor-made opportunity to explore how the concept would look in practice (Ellen MacArthur Foundation, 2012). Ellen MacArthur Foundation made (2012) their study on the process in automaker Renault's Choisy-le-roi plant. Remanufacturing and refabricating involve reusing a part that retains a significant effectivity and appearances of the original and using reverse logistics, where 90% of the spare parts collected from old cars can be reused (figure 3-14). The remanufactured parts in the plant are 30-50% less expensive and goes through the same quality control (Ellen MacArthur Foundation, 2012). The environmental impact is enormous as the remanufactured parts consume 80% less energy, 88% less water, 92% less chemical products, 70% less waster production, and the plant doesn't send any waste to landfill (Ellen MacArthur Foundation, 2012).

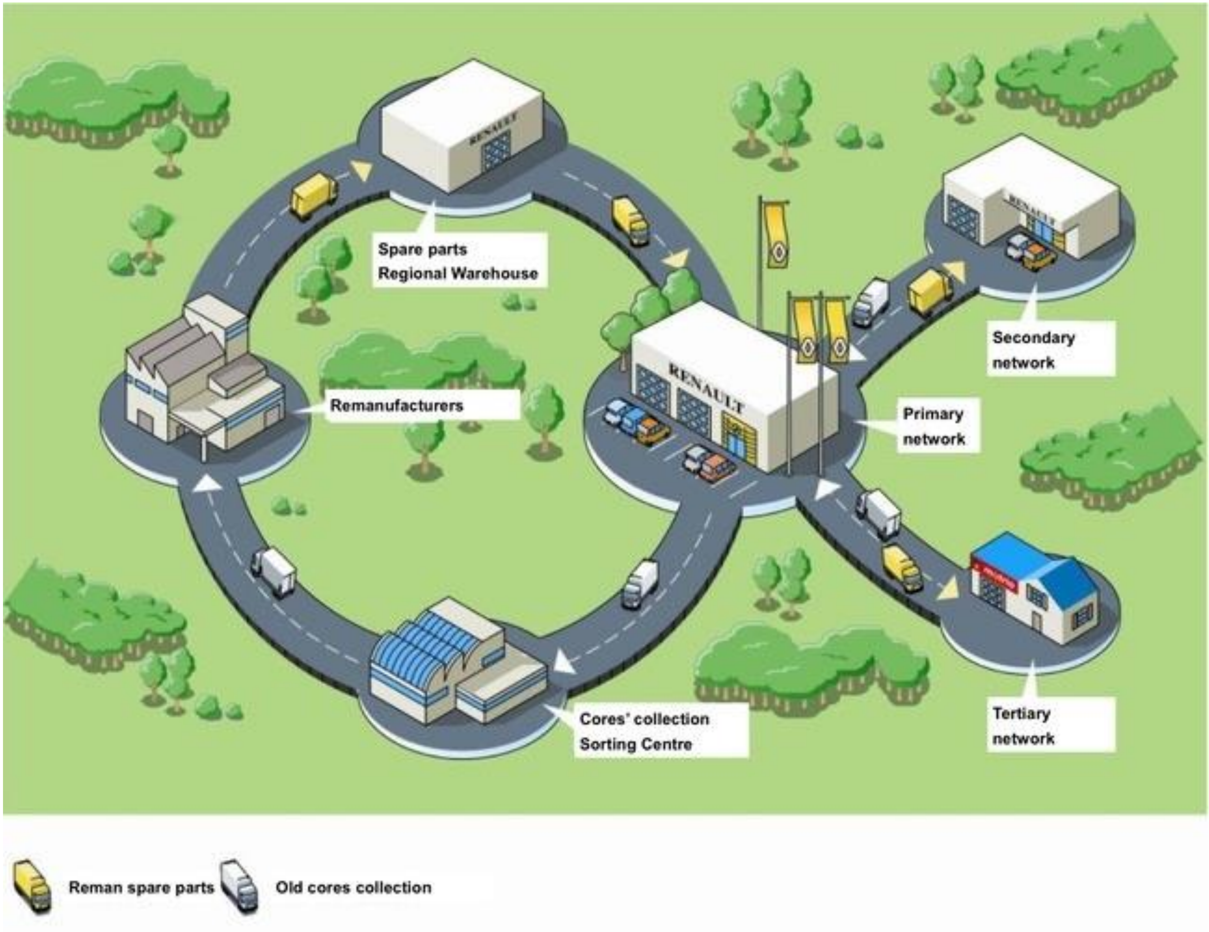


Figure 3-15: Reverse logistic network employed in Choisy-le-roy plant of Renault; from Ellen MacArthur Foundation made (2012).

3.2.3 Built environment

Building industry is the world's largest consumer of raw materials and is responsible for 25-40% of the total global CO2 emission (Pomponi & Moncaster, 2017b; WEF, 2016). The sector is expected to play a fundamental role in the CE transitioning considering their overall impact (Pomponi & Moncaster, 2017a). The elements of built environment (e.g. buildings, infrastructures, etc.) display the common characteristics of having a long lifespan, numerous components, multiple stakeholders, and materials interacting in different space and time (Hart et al., 2019).

To facilitate circularity in such complex discipline, Pomponi & Moncaster (2017a) have proposed a theoretical research framework that acknowledges the importance of interdisciplinary research and addresses both bottom-up and top-down initiatives (figure 3-14). The built environment research is framed within the natural environment research, and further scaled in three different levels; micro level manufactured components, meso level buildings, and macro level cities. Pomponi & Moncaster (2017a) further argues that the need of interdisciplinary research increases with level (figure 3-15).

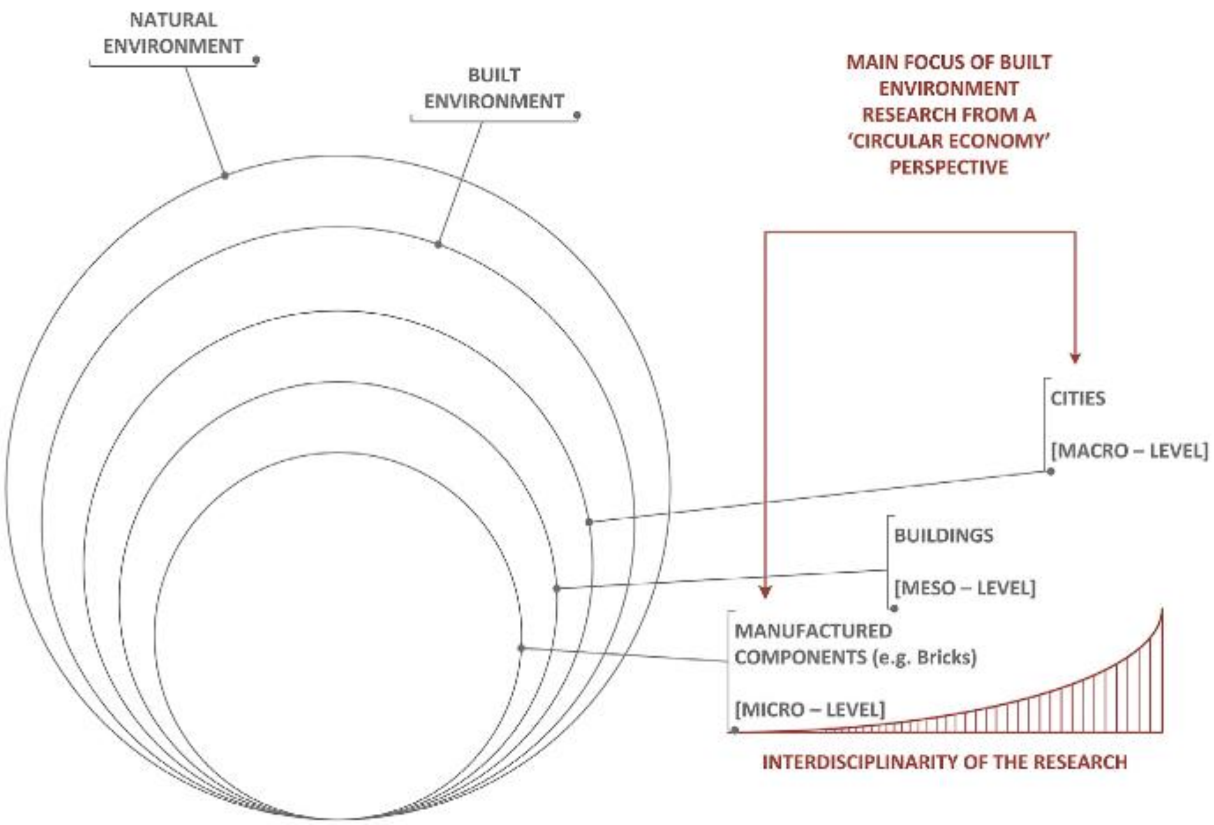


Figure 3-16: Built environment research framework; from Pomponi & Moncaster (2017a).

Since CE in the city is discussed in section 3.1, the two lower levels, building and manufactured components will be further elaborated in the sections below.

3.2.3.1 Buildings

Circular building approach is defined by Leising et al. (2018) as "A lifecycle approach that optimizes the buildings' useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a material bank". Pomponi & Moncaster (2017c) defined a circular building as "a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles".

Analytical tools

Several analytical tools are in use to demonstrate the overall environmental performances of buildings and the use of life Cycle Assessment (LCA) tools has grown in recent years largely because the environmental impact from construction is empirically shown to be of the same magnitude as that from operation (Marsh, 2017). LCA tools can assess the buildings' performance over the complete life cycle, from materials production to the end-of-life and management of waste disposal (Gervasio & Dimova, 2018). Hossain & Ng (2018) have performed a comprehensive review of literature concerning LCA implication on buildings and provides a comprehensive framework for adoption of CE principles (figure 3-16).

The framework analyses the whole building sector to enhance sustainability and details out present and extended scopes from literature (Hossain & Ng, 2018). Hossain & Ng (2018) further suggest taking resource recovery in consideration while performing LCA under the CE concept as they found in their review that most studies avoided the inclusion of material flow and waste treatment.

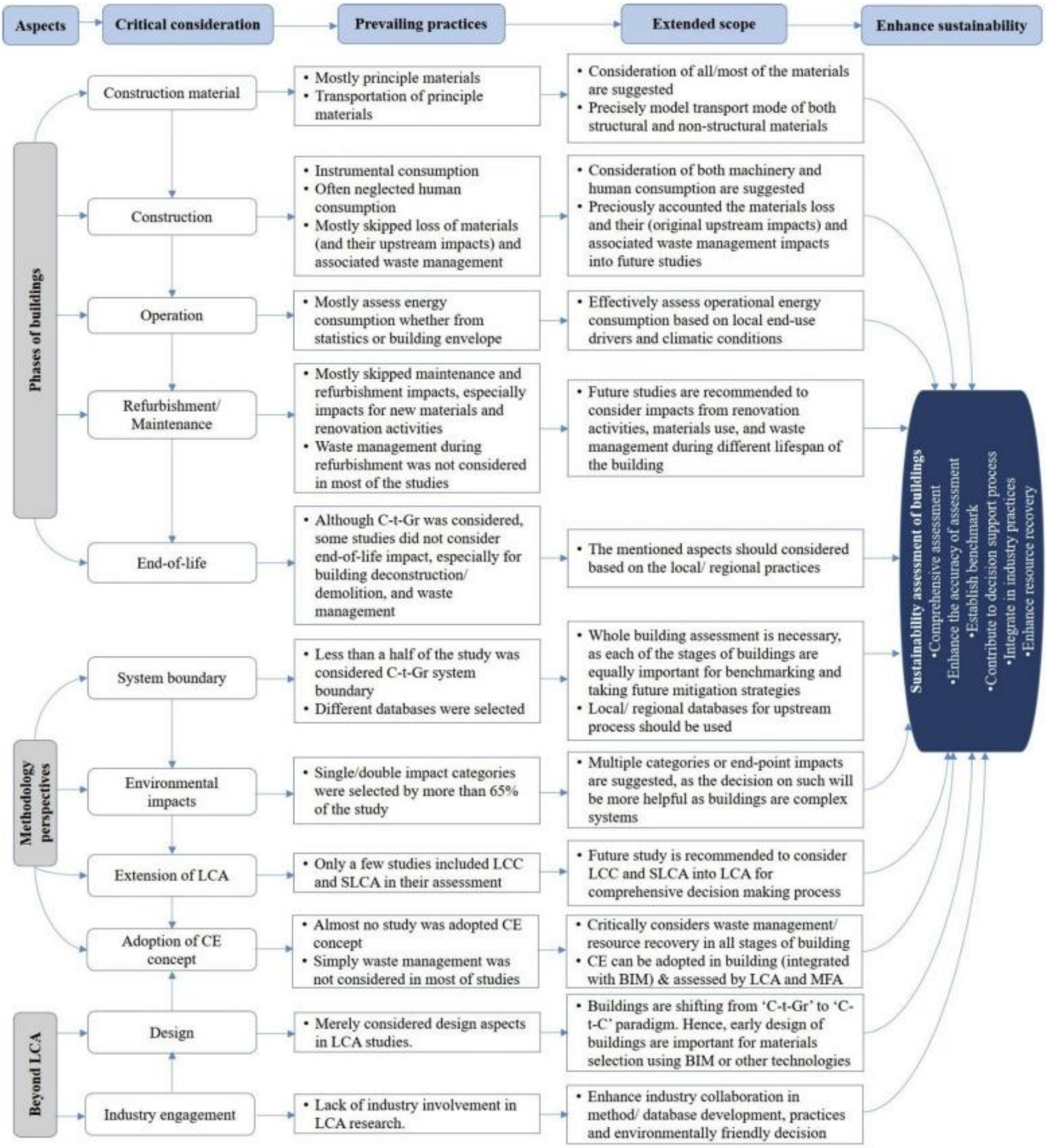


Figure 3-17: Framework for LCA research in building sector with CE adoption; from Hossain & Ng (2018).

Organizational tools

Leising et al., (2018) proposes an empirically-based tool for supply chain collaboration for contribution to the transition CE by studying three case in the Netherlands. The collaboration tool is formed from the initiating party perspective and consists of five phases: circular vision, multidisciplinary team, contract, building, and reuse of materials (figure 3-17). The authors further list a set of requirements needed for developing circular buildings:

i. a new process design where a variety of disciplines in the supply chain is integrated upfront,
ii. the co-creation of an ambitious vision,
iii. extension of responsibilities to actors along the entire building supply chain, and
iv. new business and ownership (Leising et al., 2018).

Leising et al., (2018) recommends the practitioners in the building sector to further develop collaboration tools and implement it in the earliest phase with a vison development towards circularity.

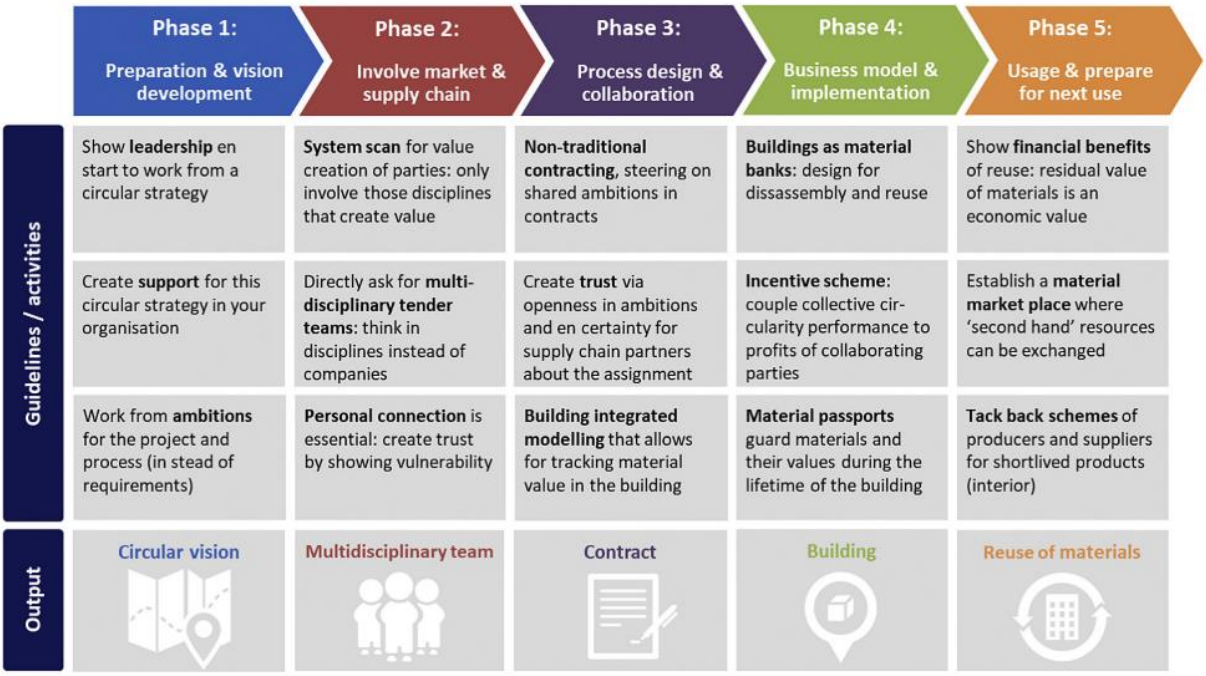


Figure 3-18:Collaboration tool for Circular Economy (CE) in Building sector; from Leising et al., (2018).

Alternative production system – Prefabricated buildings

Based on a literature review, Minunno et al. (2018) draw the conclusion that the CE frameworks on buildings are limited to concrete production and recycled concrete, and argues its relevance in CE as concrete always gets down cycled (e.g. made into a product of less value than the original such as aggregates) even when recycled. The authors then present prefabricated buildings as solution of such problems and explores seven strategies that can be used to foster circular practices in the prefabricated building sector:

Strategy 1 – eduction of construction waste and the lean production chain modern;
Strategy 2 – integration of scrap, waste, and by-products into new components many;
Strategy 3 – reuse of replacement parts or entire components reusing;
Strategy 4 – design toward adaptability (reduction through life extension) during operational stages;
Strategy 5 – design toward disassembling goods into components to be reused designing;
Strategy 6 – design for recycling of construction materials;
Strategy 7 – systems to track materials and components within their supply chain.

4 Urban land Potential in Bio-based CE: A case for Brownfields

Bio-based resources are the production inputs of the biological cycle of CE and biologically sourced products are expected to be the main driver in cutting CO2 emissions and reducing fossil fuel consumptions by providing biodegradable alternatives, such as biofuels and bioplastics (Ellen MacArthur Foundation, 2013; European Commission, 2019b; Kirchherr et al., 2017; Pimentel & Patzek, 2006). The main product of the biological cycle by a long margin is food crops and with the increasing global population, the output needs to be maintained with an even higher rate of efficiency (Figure 4-1) (European Compost Network, 2019; Vermeulen et al., 2012). The second most explored bio-based products are energy alternatives; biofuel has come a long way from being a desperate measure in the case of a fuel crisis or for land-locked countries to being considered as a viable alternative of fossil fuel at all times (Hansen et al., 2005). Production of bio-based alternatives of consumables depending on mineral sources is the less elaborate output of biological cycle but as explained in the previous sections (3.1.2.1 and 3.1.2.2), the opportunities are manifold and are getting explored for various types of products.

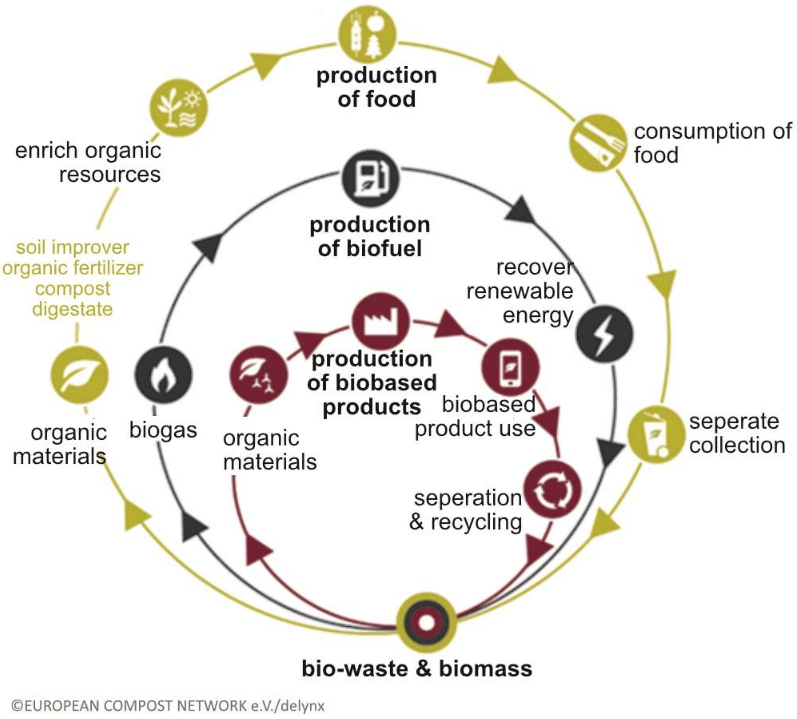


Figure 4-1: The biological cycle in the Circular Economy (CE); adapted from European Compost Network (2017).

Though, some production input of biological cycle is sourced through bio-waste, a substantial amount of input would be biomass. Soil is the medium to provide that biomass at the same time providing surface for most human activities (Breure et al., 2018). Even though a large part of the bio-based production is expected to take place outside of the cities, most of it will be consumed in the cities (UNEP-DTIE, 2012). At the same time, even in 75% urbanised Europe, cities are expanding both spatially and in population which is increasing the pressure on the rural areas that is already struggling to maintain the agrarian landscape (Bučienė, 2003; European Commission, 2017; United Nations, 2014). The loss of arable land will thus continue in the EU region which is expected to lose another 2.5 million ha by 2030, and where land abandonment is an additional factor due to the rural population loss (Bučienė, 2003; European Commission, 2017; United Nations, 2014). Considering the growing urban population that will have to depend on less and less agrarian landscape, using urban land to produce food will have a prominent role to play in addressing urban food security issues (Zezza & Tasciotti, 2010). But land is in heavy demand, especially in the cities, which by default contains a denser built fabric than that of rural areas. Still, there are still plenty of urban land, commonly known as brownfields, barren and underutilized in the cities.

Given the context of CE, brownfields can be considered as valuable waste resulting from the 'linear' land use, lands that were previously useful but now lays to waste (Breure et al., 2018; Luís Loures & Panagopoulos, 2007). Bringing the brownfields back in use can be considered a circular urban land use system while at the same time, land and soil can themselves be argued to be a non-renewable resource due to limited surface area and very slow formation (Breure et al., 2018). In the circular land use system, brownfield is considered as a resource in transition from abandonment to redevelopment and reuse (HOMBRE, 2014). The biggest constraints so far in using brownfields for food production is that they have real or potential contamination problem due to previous uses but guidelines are being developed for safe practices (Hahn, 2013; U.S. EPA, 2011). But other type of bio-based production namely cultivating bio-energy crops can take place directly on contaminated soil, simultaneously reducing ecological and human health risks, improving soil quality and providing revenue (Enell et al., 2016). Producing bio-energy crops on brownfields can also provide a solution for the long-standing critique of the practice being blamed for taking up arable land for food crop production (Breure et al., 2018; Lord, 2015; Mehmood et al., 2017).

4.1 Policy development- Defining brownfield

The term 'brownfield' can encompass varied meanings depending on the context from heavily contaminated properties to derelict industrial sites (Coffin, 2003; Luís Loures & Panagopoulos, 2007). Countries with low population densities associate brownfields with contamination while in Western Europe with high population densities and land competitiveness, relate the term with previously developed, abandoned or underused land (Oliver et al., 2005; Tang & Nathanail, 2012). Europe was a little late into addressing the issues but when they finally did in the late 1990s, they chose to see brownfields as an opportunity rather than hindrance.

4.1.1 The US context

Environmental protection and conservation begun in the US in the early 60s and Rachel Carson's book 'Silent Spring' documenting the impact of pesticides bolstered the environment movement across the general public (Griswold, 2012; Skelly, 2017; US EPA, 2018). US EPA[9] was established in 1970 but their first major environmental endeavour didn't take place until 1978 following 'The Love Canal Tragedy'. Love Canal is a neighbourhood in upstate New York which was built upon a chemical dumpsite. After a heavy monsoon of 1978, a group of homeowners complained about chemicals leaking into their basements. The pollution was later linked with severe health threats and US EPA had to temporarily relocate 700 families. Hooker Chemicals who sold the place in 1953 was sued for 100 million USD by the state in 1979 (Beck, 1979; Gorman, 2003; US EPA, 2018). These events focused attention of the public to the contaminated properties and the central government promptly responded with a law that allows them to hold the polluters responsible.

US Congress enacted CERCLA[10]or what is commonly known as the 'Superfund Act' in 1980 (Meyer, 2003; US EPA, 2004). The act gave EPA authority to 1) create a national priority list of sites potentially dangerous to human health or environment (later known as Superfund sites), and 2) remediate them by compelling the parties responsible for pollution to clean up under the 'polluters pay' principle (US EPA, 2020c). The Act's strict focus on liability along with the stigma associated with contamination made even the sites only suspected of contamination less and less desirable to the developers (Gorman, 2003). Thus, the need for a new term arose that would distinguish less polluted properties from severely polluted Superfund sites.

The term 'Brownfield' was first used in 1992 at a U.S. congressional hearing and although the term was known, it had been used sparsely among urban planners since the 1970s (Jones & Welsh, 2010). Different states have enacted laws (e.g. Act 2 of Pennsylvania) and more recently, in 2001, the federal government passed the Small Business Liability Relief and Brownfields Revitalization Act (more commonly known as the 'Brownfield act') to facilitate brownfield regenerations responding to the concerns of business and community leaders for the growing numbers of brownfields (Gorman, 2003; Maldonado, 1996). The act official definition provided by the act stands:

'Real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant'(Brownfield Act, 2002).

The Brownfield act helped codify EPA's practice and action in to a legal document but even before, since the mid-1990s, EPA has been providing local authorities seed money to launch rehabilitation and clean-up projects on brownfield sites (US EPA, 2020a). The EPA initiated the 'Brownfield program' in 1995 and with the recent BUILD act (Brownfields Utilization, Investment and Local Development) passed in 2018, it retains the authority to work continuously in managing over 450,000 brownfield sites in the USA (US EPA, 2020a). The policy transition towards a specific definition for brownfields in the USA is summarised in figure 4-2.

[9] United States Environment Protection Agency

[10] Comprehensive Environmental Response, Compensation, and Liability Act

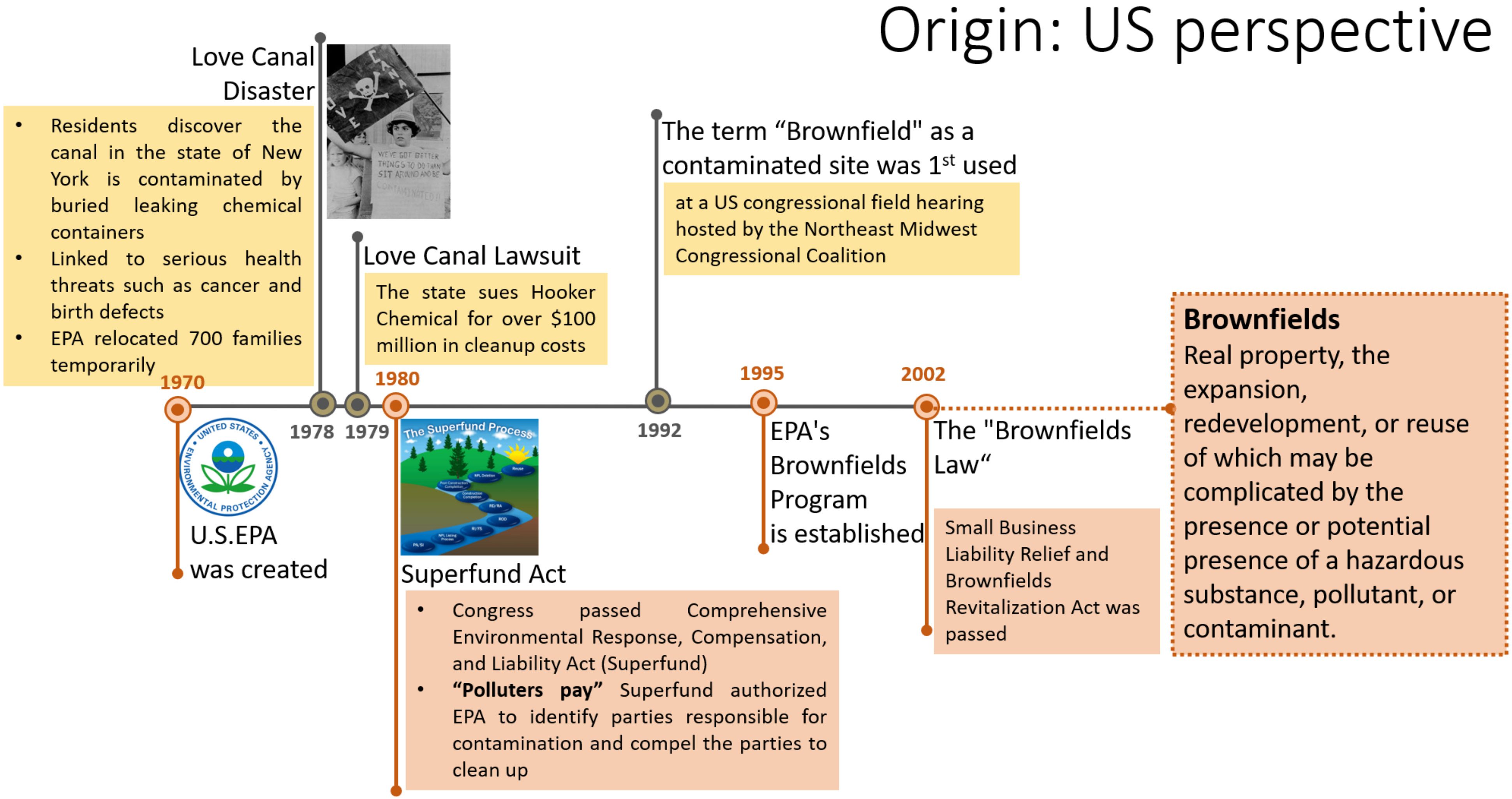


Figure 4-2: Timeline of the policy development towards Brownfield definition in the US.

4.1.2 The EU context

Considering the 200 years old industrial past of the EU, the continent is teeming with contaminated sites (~342 000) and potentially contaminated sites (~2.5 million), and their restoration has been a major issue in many European countries since the 1980s (Alexandrescu et al., 2014; Vanheusden, 2009). But unlike the USA, where US EPA provides a legal definition for Brownfield, there's none so far in the EU. The term is soon accepted in UK but is not consistently used among the 28-member countries with 24 official languages as many countries have their own terminologies (Germany: brachflächen, France: terrains abandonnés, Hungary: felhagyott területek). The lack of consensus is not limited only to terminology since there is neither a common definition for brownfields nor a centralized policy commonly agreed within the European Union (EU) (Carlon et al., 2009; EUGRIS, 2018).

The first United Nations (UN) conference on the human environment took place in Stockholm (SE) in 1972 that set up the foundation for systematising environmental concern as well as planning concrete environmental policies (United Nations, 1973). On the basis of the European Council commitments, the first Environmental Action Programme (EAP), a 5 year action plan, was decided upon in 1973 (Hey, 2005; United Nations, 1973). With continuous progress with consecutive EAPs, the fourth EAP (1987-1993) established the groundwork for the European Environment agency (EEA) which was established in 1993 (site).

CABERNET (Concerted Action on Brownfield and Economic Regeneration Network), was a pan-European research project funded under the fifth framework programme (1998-2002) and uses the term 'brownfield' as a reference. The project intended to provide network of management strategies, tools, and a framework for coordinated research activities by creating a platform for a diverse group of stakeholders to share their experience (Ferber et al., 2006). CABERNET defined brownfields as sites that:

- have been affected by former uses of the site or surrounding land;
- are derelict or underused;
- are mainly in fully or partly developed urban areas;
- require intervention to bring them back to beneficial use, and may have real or perceived contamination problem (Dixon et al., 2007; Ferber et al., 2006).

This definition was further adopted by subsequent research projects under the Seventh Framework Programme (FP7, 2007 to 2013), TIMBRE (Tailored Improvement of Brownfield Regeneration in Europe) and HOMBRE (Holistic Management of Brownfield Regeneration) (Bartke, 2013; HOMBRE, 2014). Under the same fifth framework programme that funded the CABERNET, another project, EUGRIS (European groundwater and contaminated land remediation information system), launched a web portal that has updated information on contaminated soil and water across Europe (EUGRIS, 2020a). The EUGRIS web portal is supported by a co-operative community of collaborating projects, people, and organisations working on topics related to soil and water across Europe who uses this platform to dissiminate their state of the art research findings (EUGRIS, 2020b).

The EU member states are also working towards nationalizing their concerns in dealing with contaminated sites; by 2017, every EU member state adopted the ‘polluters pay principle’ in their national policy (Paya Perez & Pelaez Sanchez, 2017). Only about 15% of the 342,000 contaminated sites have been remediated with new ones being discovered simultaneously, so it is suffice to say that the field of brownfield remediation has a long way ahead (EEA, 2014; Pérez & Sánchez, 2015). Brownfield regeneration received further attention when it started to be seen as an instrument to achieve the ‘No net land take by 2050’ goal by EU (COM/2011/0571). To achieve the target of no net land take by 2050, the EU Environment Action Programme (7^{th} EAP, 2015-2020) is designed to put policies in place by 2020 (European Commission, 2016). For better understanding of the policy transition, a timeline for EU policy development is presented in the figure 4-3.

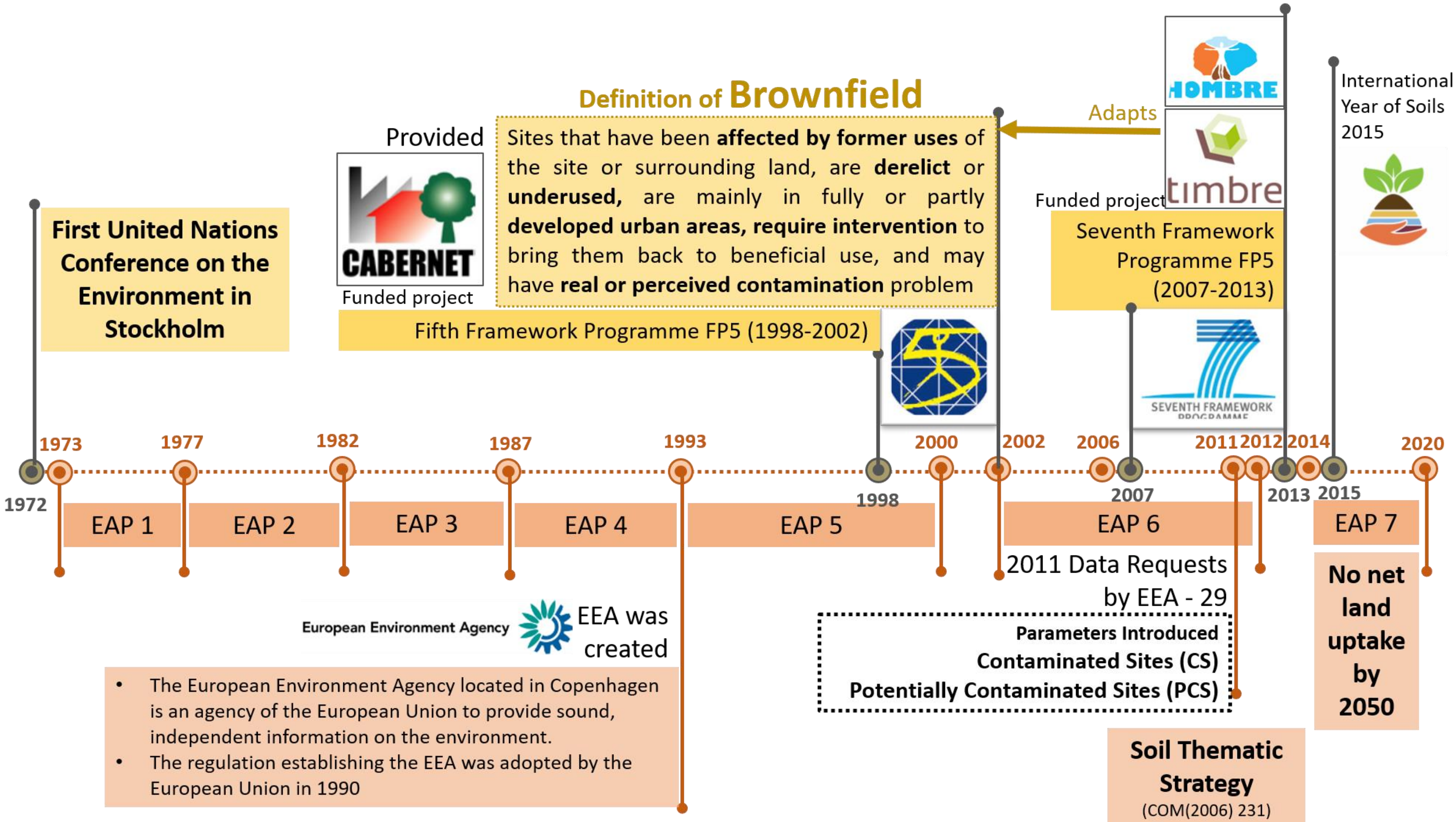


Figure 4-3: Timeline of the policy development towards Brownfield definition in the EU.

4.2 Remediation and repurposing of brownfields

Brownfield redevelopment is considered both sustainable and necessary at a time when 'greenfields', i.e. previously undeveloped land, are both scarce and expensive (Pediaditi et al., 2010; Pizzol et al., 2016). Remediation processes can be categorized in various ways; grouped by approaches (e.g., engineering, process-based and hydraulic/natural) (Wood, 2001), type of technology used (e.g., biological, chemical or physical) (Scullion, 2006), or location (e.g., in-situ or ex-situ) (Reddy, Adams, & Richardson, 1999). Basically, remediation options are selected based on their ability to achieve the required risk reduction level for future use and, at the same time, satisfy time, cost and place restrictions (Scullion, 2006). Brownfield redevelopment can be categorised based on two key aspects: availability of time and resources, both financial and physical, for redevelopment (Table 4-1). The categorization is further elaborated with a common brownfield example: gasworks. Gasworks are industrial plants for producing flammable gas from coal and was the principal means of gas production in Europe when it was first commercialised in the early 19th century (Peebles, 1980; Thomas & Lester, 1994). Once found in every town and city, the coal gas plants went on decline when the use of natural gas became more commonplace and started to get abandoned (Johnson, 2013). There's a possible 5,000 abandoned gasworks sites in the UK alone (Thomas & Lester, 1994). Though the degree of contamination can vary, most investigated sites are found to be contaminated with coal tar (Thomas & Lester, 1994).

Time span - Short, Resources – low: Temporary use

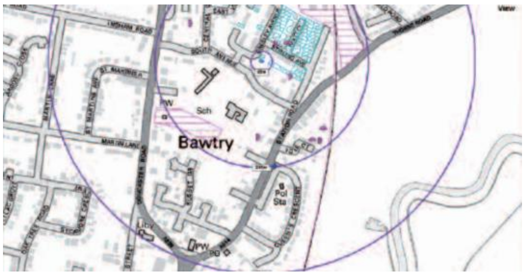
When brownfields do not pose an immediate threat to human health but at the same time, are not attractive to developers, e.g. because of stigma associated with contamination or low land value, and there is no responsible part that authorities can act against, sites risk being underused and untreated for a long time. Some, such as the abandoned Tempelhof airport in Berlin, can still self-regenerate as a hub for local gathering and spontaneous activities (Németh & Langhorst, 2014).

The CiBoGa project in Groningen (the Netherlands) dealt with the Ebbingekwartier gasworks site in a rather innovative way by planning a temporary use of the existing structure beforehand and integrating the use in the overall plan of development. The abandoned gasworks site was scheduled to be developed as a housing project and considering the scale of the project and site, the development was phased (Maare & Zinger, 2004). The developers decided to use the existing gasworks buildings for various temporary usage before they were scheduled for dismantling such as exhibition hall in the old porter's lodge, large villa for meeting and workshops (Maare & Zinger, 2004).

Time span - Long, Resources – low: Ruderal/Derelict

Unfortunately, many brownfield sites are not fortunate enough to be part of a future infrastructure development and get remediated in the process, or self-regenerate with local or structured initiatives. Even when they are of historic interest, abandonment and lack of care can make heritage properties destroyed beyond repair. The railway gasworks, the oldest industrial building in New Westminster (Canada) built in 1886, shared such fate when the roof finally collapsed during a storm in 2016 after elongated negligence by the provincial government who took over the site after abandonment (Talmazan, 2016). Brownfields like Solventul petrochemical plant in Romania and Chatterley Whitfield colliery in the UK, remain derelict because the benefit is too uncertain in comparison to investments in expensive and extensive dig and dump remediations (Historic England, 2018; Voiculescu & Jucu, 2016).

Table 4-1: Categorisation of brownfield redevelopment including the examples described in the text.

Time span / **Resources**	Short term	Long term
High	**Conventional remediation** Examples: Bawtry Gasworks, UK • Developed into a housing estate • Contamination was discovered later in 48 properties • All structures were removed together including all contaminated soils to a depth of at least 0.6m  Image source: Landmark Information Group (2006).	**Gentle Remediation Options (GROs)** Example: Gasworks park, Seattle, USA • Currently a public park containing the remains of the sole coal gasification plant in the US • Used primarily phytoremediation to remediate  Image source: Richard Haag Associates (2020).
Low	**Temporary use** Example: Ebbingekwartier (CiBoGa project) Groningen, the Netherlands • Former gasworks was part of a phased development of a new housing neighborhood • Many of the old buildings were put in temporary use such as exhibition hall in the old porter's lodge, large villa for meeting and workshops  Image source: Wikimedia commons (2017).	**Ruderal/ derelict** Examples: Railway Gas Works, New Westminster, Canada • Abandoned site owned by provincial govt. containing the oldest industrial heritage building. • The roof was destroyed in a storm in 2016 and finally the building was demolished in 2017.  Image source: Talmazan (2016).

Time span - Short, Resources – High: Conventional remediation

Conventional remediation options such as in-situ containment is an efficient technique that can achieve satisfactory level operational safety. Containment was used in famous examples of environmental scandals like Love Canal in the USA in 1978 and Lekkerkerk in the Netherlands in 1980 (Scullion, 2006). Both cases generated massive negative public attention which forced the political authorities to take immediate action and establish policy and regulation (Pollard et al., 2001). Even though immediately effective, in-situ containment carries the risk of failure in the long term due to lack of proper design or maintenance. For example, contamination on site may cause groundwater contamination through leakage, which typically is more expensive and complicated to clean than contamination in soil (Wood, 2001). In the case of the Bawtry gasworks, the plant was abandoned in the 60s and contamination was detected well afterword; in 2001 when the site was already redeveloped a housing estate (UKELA, 2018). A resident discovered tar pits while digging in the garden and it was then realised the underground containers were never removed (UKELA, 2018). The contaminated site was later remediated by using another conventional remediation technique, ex-situ disposal of contaminated soil, more commonly known as ‘dig and dump’ (Pérez & Sánchez, 2015; UKELA, 2018).

Today, sites that are situated in or near densely populated areas with high land value, and which poses unacceptable human health risks, are in high-income countries typically quickly dealt with and are funded swiftly by the liable party (Arias Espana et al., 2018; Kanda et al., 2018; Ramírez-Hernández et al., 2018). In fact, almost every land development in inner city areas is expected to deal with contamination due to its previous use or surrounding activities, including heavy traffic. New developments typically require excavation as part of their construction, thus dig and dump is often a favourable option. Despite being quick and safe in terms of contaminant removal, dig and dump remediation processes may cause a lot of secondary negative impacts due to the remedial activity, e.g. traffic risks due to transports, emissions of CO_2, noise, and consumption of non-renewable resources such as fossil fuels and gravel as refilling material (Bardos, 2014; Bardos et al., 2011; Rosén et al., 2015).

Resource investment is expected to be ‘high’ for this type of remediation because GROs are more data intensive and would require expert and novel knowledge on various subjects to design a suitable one. But even then, if compared with the monetary valuation, conventional ‘hard remediation’ is going to remain a costlier alternative even withholding the impact on the environmental.

Time span - Long, Resources – High: Gentle Remediation Options (GROs)

The international consensus on promoting alternative, more sustainable methods and low cost, low impact remedial measures for bringing abandoned brownfields back in use is growing in the face of the growing concerns over the unsustainable traits of the conventional remediation processes (Norrman et al., 2016; Rosén et al., 2015b; Smith, 2019). For example, the UK Sustainable Remediation Forum (SuRF-UK) framework adopts a multiple stakeholder approach to assess the sustainability of remediation action by reviewing and evaluating a wider set of benefits and impacts (Bardos et al., 2011). The Ruhr region of Germany, one of the densest metropolitan areas in Europe, took one such step where they deployed long-term remediation through natural processes on 10,000 Ha of some of the most contaminated sites in the Emscher corridor. These sites were developed as ‘industrial forests’ to offer the inhabitants the much lacked opportunity to enjoy greenery (Dettmar, 2005; Erdem & Nassauer, 2013; Franz, Güles, & Prey, 2008; Hamm, 2006). Landscape architect Peter Latz’s work on Duisburg Nord layers old industrial structures with vegetation to remediate the soil (i.e. phytoremediation). The project took 22 years to realize its full potential and sets the legacy for urban derelict land reclamation where the past is embraced, not discarded (Latz et al., 2016; Loures & Panagopoulos, 2007).

The Seattle gasworks park in the USA followed similar processes of the development as the Emscher corridor. The gasworks stopped operating in the 1956 and was being used as a landfill and waste dump until the local government decided to buy the land back for redevelopment in 1963 (Gao & Liang, 2013). The site was found to be contaminated various contaminants due to the previous activities with PAHs, volatile organic compounds, trace metals, and cyanide (Turney & Goerlitz, 1990). Landscape architect Richard Hagg was in charge of the development of the site into a landscape park and like Peter Latz, he also decided to put forward the industrial heritage importance and keep most of the old furnace structures intact (Gao & Liang, 2013). The remediation plan took the ecological properties of the site and the surroundings under consideration and specialists were consulted to develop a remediation plan with minimum intervention and opting with biological processes to remediate as much as possible (M. Gao & Liang, 2013; Hart Crowser, 2020).

4.2.1 Gentle Remediation Options (GROs)

Tree covers on brownfields are found to be a low-cost and effective solution to bring the derelict lands back in use in England (French et al., 2006). At the same time, vegetation can offer more passive remediation alternatives to the resource intensive conventional remediation processes to address brownfield regeneration (Kennen & Kirkwood, 2015). Phytoremediation technologies are proven to be efficient for both contaminated soil and water, and at the same time helps to maintain the biological functions (Cundy et al., 2013; Juwarkar et al., 2010). Use of plants for remediation (phytoremediation) is a Gentle Remediation Option (GRO); other GROs include technologies using fungi and/or bacteria-based methods, with or without chemical additives or soil amendments (Bardos et al., 2008; Onwubuya et al., 2009).

Cundy et al. (2013) defined GROs as risk management strategies that result in a net gain (or at least no gross reduction) in ecological soil functions, as well as achieving effective risk management. Some common examples of GROs are briefly presented in table 4-2. The remediation potential for GROs varies greatly based on type of contaminant, the time available, and the phytoremediation mechanism used for remediation (Kennen & Kirkwood, 2015). Based in such factors, phytoremediation and phytomanagement technologies are mapped in the figure 4-4 based on their potential for remediation. Phytostabilisation is very suitable for both organic and inorganic contaminants though the remediation time is quite high for metalloids (Figure 4-4) (Kennen & Kirkwood, 2015; OVAM, 2019). Degradation of chlorinated solvents and petroleum products and evapotranspiration by phytovolatilization are also highly suitable GRO technologies for field application (Figure 4-4) (Kennen & Kirkwood, 2015; OVAM, 2019).

Table 4-2: Examples of Gentle Remediation Options (GROs); adapted from (Cundy et al., 2016).

GROs	Descriptions
Phytodegradation/ phytotransformation	Use of plants (and associated microorganisms) to uptake, store and degrade or transform organic pollutants.
Phytovolatilization	Use of plants to remove pollutants from the growth matrix, transform them and disperse them (or their derived products) into the atmosphere.
Phytoextraction	The removal of metal(loid)s or organics from soils by accumulation in the harvestable biomass of plants. When aided by use of soil amendments (e.g. EDTA or other mobilising agents), this is termed “aided phytoextraction”.
Phytostabilisation	Reduction in the bioavailability of pollutants by immobilization in root systems and/or living or dead biomass in the rhizosphere soil.
Rhizodegradation	The use of plant roots and rhizosphere microorganisms to degrade organic pollutants.

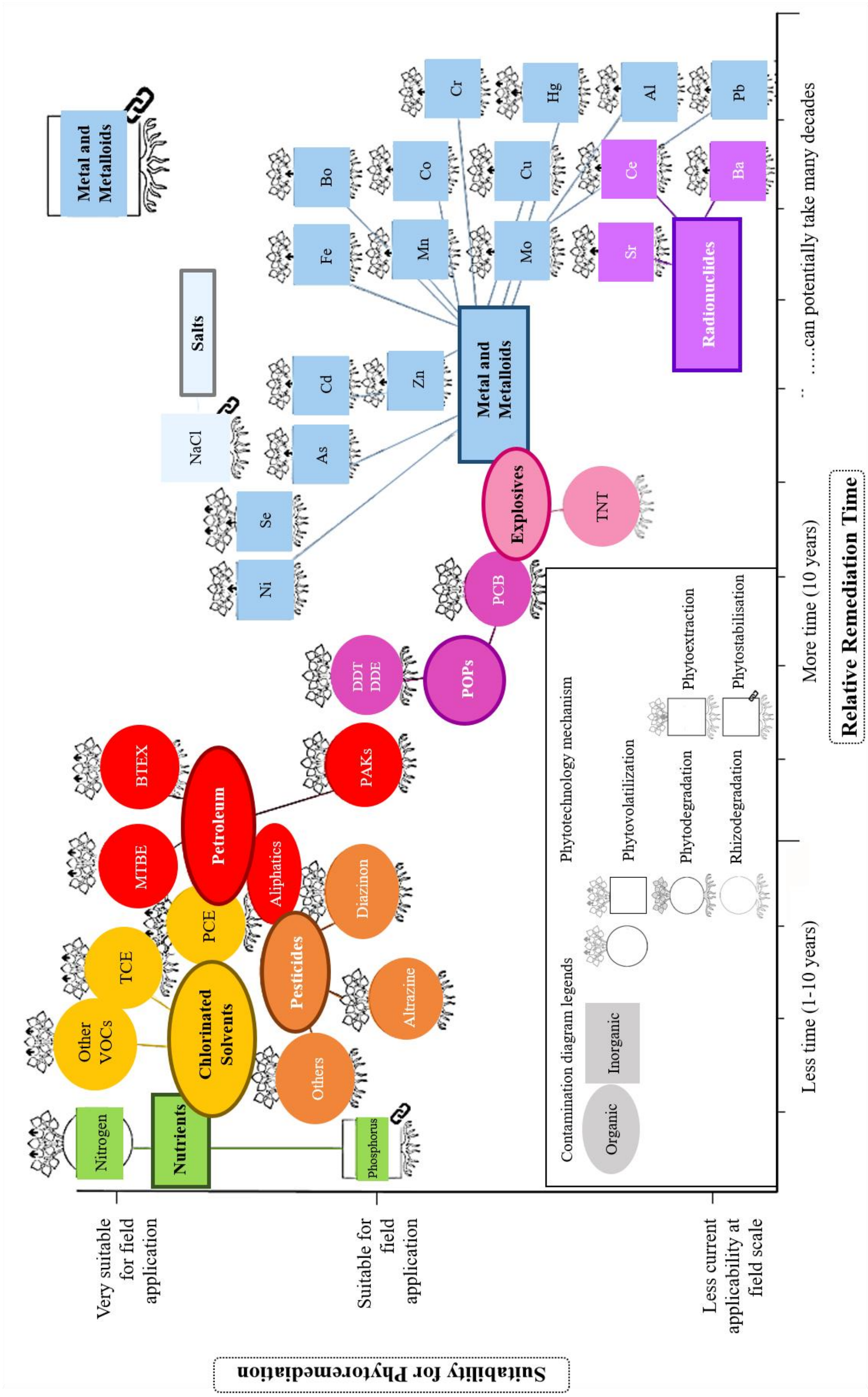


Figure 4-4: Overview of the phytoremediation potential of some contaminants and associated phytoremediation mechanism (from OVAM, 2019 and Kennen & Kirkwood, 2015).

GRO technologies are best applicable for 'green' reuse of a site, such as urban parks, bioenergy crops production, and urban agriculture (Cundy et al., 2016; Erdem & Nassauer, 2013; Evangelou et al., 2012; 2015; Fässler et al., 2010; HOMBRE, 2014; Huang et al., 2011; Tripathi et al., 2016). GROs, if properly implemented, can have a significantly lower deployment cost than conventional remediation techniques. There are a wide range of benefits that can be provided by GROs, table 4-3 presents a summary of such. Smartly planned vegetation can be an end use in itself (e.g., parks, cropland) but can also be maintained temporarily until the risk level allows for more intensive land-use (Cundy et al., 2016). Brownfields that are deemed unfit for development can thus still have the opportunity to be beneficial e.g. by harvesting the vegetation while simultaneously remediating the soil from contaminants.

Table 4-3: Examples of wider benefits from implementing GROs; adapted from Cundy et al. (2016).

General benefits	Specific benefits
Risk Mitigation of Contaminated Land and Groundwater	• Biosphere (including human health) • Water resources (hydrosphere)
Soil improvement	• Fertility and soil structure
Water resource improvement	• Water resource efficiency and quality • Flood attenuation and capacity management • Rehabilitation of water resources
Provision of green space	• Enhancing ecosystem services • Enhancing local environment
Mitigation of anthropocentric climate change	• Renewable energy generation • Renewable material generation • Greenhouse gas mitigation
Socio-economic benefits	• Amenity • Economic assets

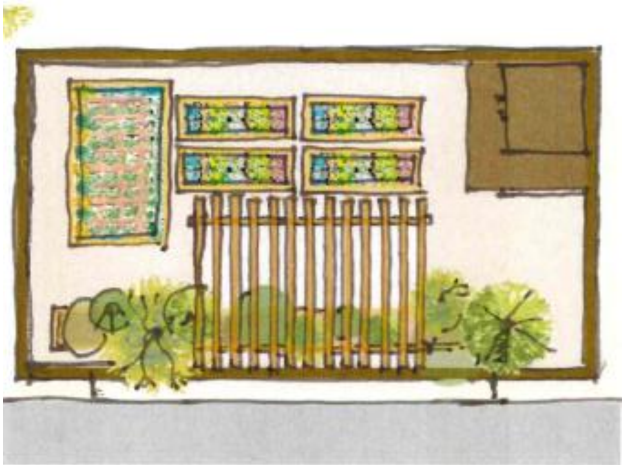
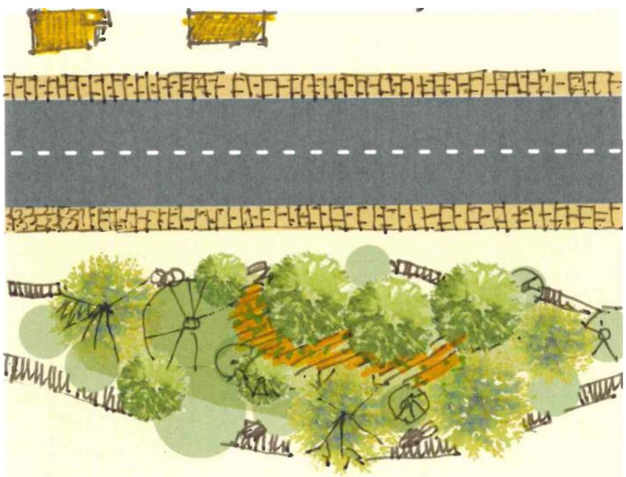
4.3 Bio-based land use on Brownfields

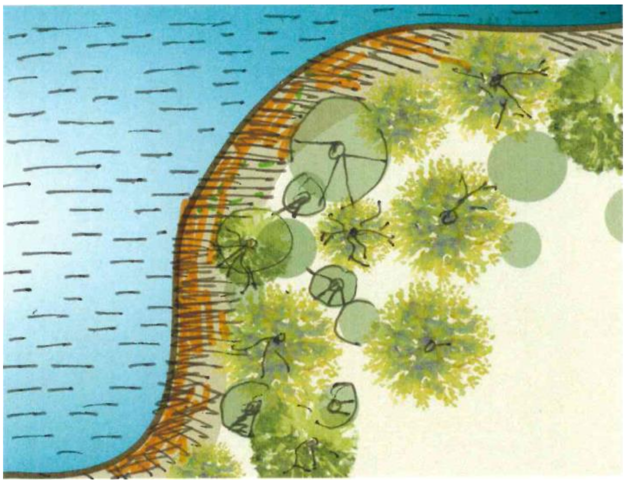
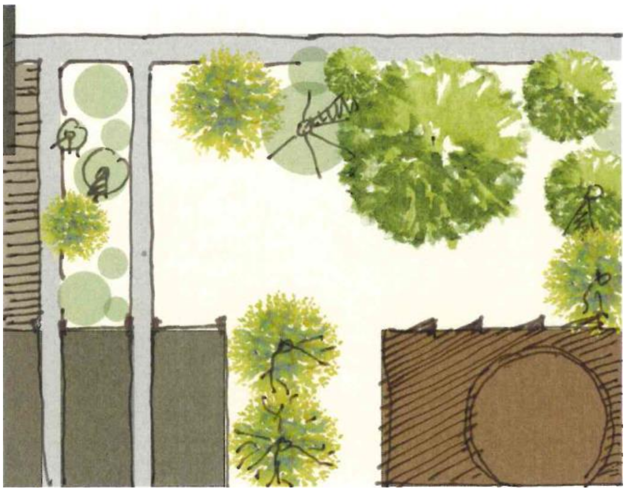
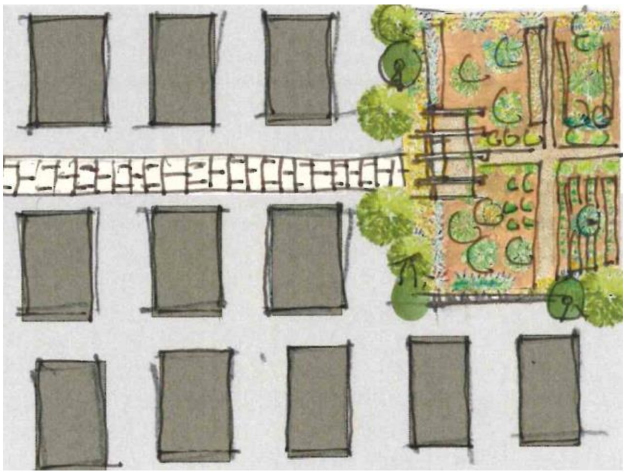
Cities consists largely of built-up areas, but a significant part of the urban fabric are urban open spaces that are not yet urbanized. As the city population continue to rise, the pressure to develop the less appreciated open areas is expected to rise (Chiesura, 2004a; Ståhle, 2010). Greenspaces can be described as vegetated open spaces that are proven to be essential for the physical and mental well-being of the citizens as well as providing a multitude of ecological functions (Bowler et al., 2010; Kaplan et al., 1983; Oke et al., 1989; Ståhle, 2010; Ulrich, 1981). To capture the diverse services of urban greenspace (UGS), Sandström (2002) introduced the concept of 'green infrastructure' which he describes as equally instrumental in achieving sustainable urban development as any 'technological infrastructure'. Green infrastructure can be understood as 'an interconnected network of greenspaces that conserves natural ecosystem values and functions, and that provides associated benefits to human populations' consisting of all natural habitats in an urban area, also including blue spaces such as lakes or rivers (Benedict & Mcmahon, 2001, p. 5).

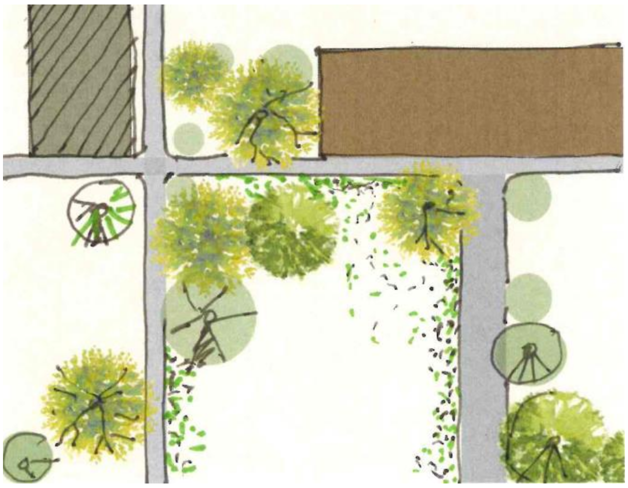
There are many variants of UGS and there are also equally many ways to categorize them. In this report, the typology made by Green Surge, a pan-European research collaboration of 24 institutes of 9 countries funded by EU, is used (Haase et al., 2015). Green Surge created an inventory of 44 types of

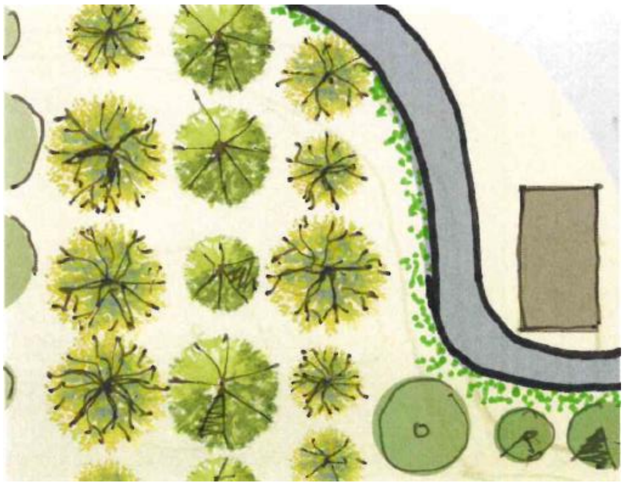
UGSs that are further categorized in 8 main categories that takes blue spaces (water bodies), grey spaces as well as several greenspaces that can be found in the close proximities of cities in to consideration (Cvejić et al., 2015). The study made use of the already existing pan-European data sets, the Urban Atlas and Corine land use/land cover (CLC) to create the inventory (Copernicus EU, 2020a, 2020b; Cvejić et al., 2017). Among the 44 elements in the inventory, brownfields can be considered listed as the element ‘abandoned, ruderal and derelict area’ (UGS element 33) which is further elaborated as ‘Recently abandoned areas, construction sites, etc. with spontaneously occurring pioneer or ruderal vegetation’ (Cvejić et al., 2015). Fourteen selected UGS inventory are further elaborated in the table 4-4 below.

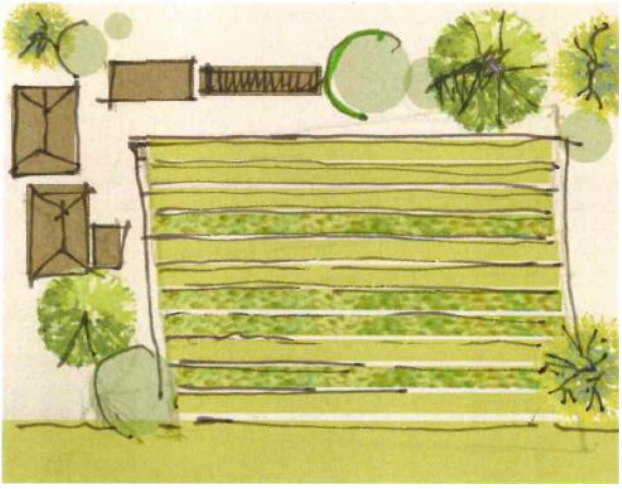
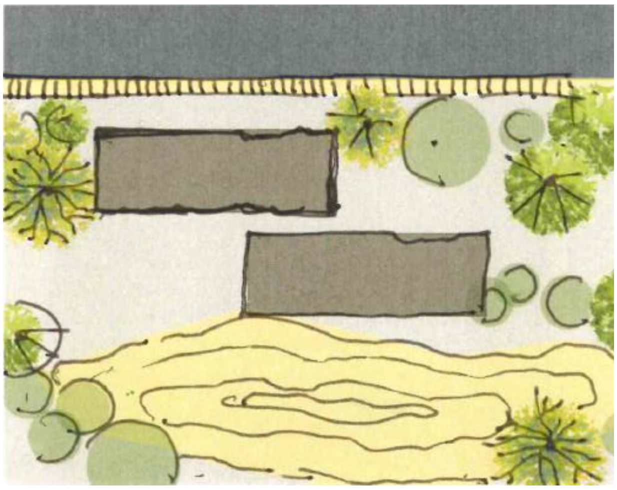
Table 4-4: The studied list of potential future green land use on urban brownfields derived from the Urban Greenspace (UGS) inventory by GREEN SURGE (Haase et al., 2015). Illustrations are created by the author.

Name	Description
Building greens 	Building greens refer to plants on balcony, roof, or any place within a building (Cvejić et al., 2017). They are mostly potted plants but use of planter boxes are not uncommon, especially for rooftop gardening if the building is large enough (Cvejić et al., 2017; Livingroofs, 2020).
Bioswale 	Bioswales are defined as ‘vegetated, shallow, landscaped depressions designed to capture, treat, and infiltrate stormwater runoff as it moves downstream’ (NACTO, 2020). Bioswales are greater in length than width, often designed with engineered soils and vegetated mainly with both drought and flood withstanding plants (SSSA, 2020).

Riverbank Green/ riparian vegetation 	Riparian vegetation or riverbank greens, also known as fringing vegetation, grows along banks of a waterway extending to the edge (WA Water, 2020). Wetland vegetation can include trees, a shrub or a ground layer consisting of herbs, grasses or their combination in shallow aquatic areas while submerged aquatic vegetation can be found in deeper wetlands (Wetland Info, 2020). For public use, these areas usually accessorized with foot or bike paths (Cvejić et al., 2017).
Historical park/garden 	Historical parks are similar to large urban parks, but with elements that are necessary to ensure the heritage status and thus, requires distinct management (Cvejić et al., 2017). Examples of abandoned industrial sites turned into parks later on includes Seattle gasworks park, Duisburg Nord park, Emscher park, etc.
Neighbourhood greenspace 	Neighbourhood greenspace is characterized by Cvejić et al. (2015) as 'semi-public green spaces, vegetated by grass, trees and shrubs in multi-story residential areas.'

Institutional greenspace 	Institutional greenspaces are green spaces in and around public and private institutions and corporation buildings (Cvejić et al., 2017).
Allotment 	Allotments are small parcels of rented to people for mostly non-commercial production of fruits, vegetables, flowers, etc. (Cvejić et al., 2017; NSALG, 2020). Allotments were first conceptualized in the 19th century to help the urban laboring poor to cultivate their own food but more recently, the recreational purpose is also very dominant (Boström, 2007; NSALG, 2020). As of 2007, there are about 42000 allotment renters in Sweden alone (Boström, 2007).
Community garden 	Community gardens are defined as sections of land collectively gardened by a community for the specific purpose of growing fruits, vegetables and/or herbs for self-consumption (Egli et al., 2016; Ginn, 2012).

Grassland 	Grasslands are open and mostly flat lands with a grass cover that exists in every continent except Antarctica and relative to definition, consists of 20-40% land area of the world (Nunez, 2019).
Tree meadow/ meadow orchard 	Tree meadows or orchard meadows are composed of scattered fruit trees within semi-natural grassland which in turns can be used for grazing (i.e. mixed agricultural use) (Cvejić et al., 2017; Plieninger et al., 2015; Rabenhorst, 2020). Scattered trees cover almost 55,000 km^2 of farmlands in Europe (Plieninger et al., 2015).
Biofuel production / agroforestry 	Biofuel production refers to land specifically devoted energy crop production like short rotation coppice or poplar, etc. (Cvejić et al., 2017). Biofuel crops make little contribution to biomass supply needed for biofuel production so far and in Europe, most of the cultivation (80-85%) is of rapeseed for biodiesel production (Ericsson et al., 2009).

Horticulture/ arable land 	Horticulture or arable land are defined as land devoted for commercial production of vegetables, flowers, berries, etc. (Cvejić et al., 2017).
Shrubland 	Shrublands are made of shrubs (i.e. short trees or hedges) with grass covers in between and thrive on areas where the climate is not favourable to support tall trees (NASA Earth Observatory, 2020).
Spontaneous vegetation 	Spontaneous vegetation refers to spontaneously occurring pioneer or ruderal vegetation, more specifically those occurring on brownfield sites (Cvejić et al., 2017).

4.4 Services provided by bio-based land uses

Ecosystem functions are ‘the habitat, biological or system properties or processes of ecosystems’ and ecosystem services refers to ‘the benefits human population derive, directly or indirectly, from ecosystem functions’ (Costanza et al., 1997). Even though the human population is dependent on functioning ecosystem services, valuation of these are difficult and requires non-market valuation methods (Lazo, 2002). They are however, increasingly making their way into economic discussions since Costanza et al. (1997) provided the estimates of the value of seventeen ecosystem services (e.g. food production, climate regulation, raw materials, etc.) being double of the global gross national product on average. The values and services provided by ecosystem can be categorised in many ways and the widely used categorisation provided by The Economics of Ecosystems and Biodiversity (TEEB) is presented below:

- **Provisioning services** – food, raw materials, fresh water, and medicinal resources;
- **Regulating services**- local climate and air quality, carbon sequestration and storage, moderation of extreme events, waste-water treatment, erosion prevention and maintenance of soil fertility, pollination, and biological control;
- **Habitat or supporting services** - habitats for species and maintenance of genetic diversity;
- **Cultural services -** recreation and mental and physical health, tourism, aesthetic appreciation and inspiration for culture, art and design, and spiritual experience and sense of place (TEEB, 2020).

Though cities are where the human population live at large and with increasing concentration, the city dwellers depend on functioning ecosystem outside of the urban periphery (Folke et al., 1997). Managing and utilizing the urban ecosystems can thus be the key to address such challenges (Maes et al., 2016). Withstanding the provisioning services, UGSs provide many non-material educational and recreational benefits, and most importantly, greenspaces in the cities can be directly associated with citizen wellbeing (Chiesura, 2004b; Maes et al., 2016). But only the provisioning ecosystem services such as food and biomass has been part of the discussion so far as a biological resource in the bio-based CE (European Commission, 2019a; TEEB, 2010). Limiting the discourse only to food and biomass, especially in the cities, would fail to capture other vital services provided by the greenspaces to urban dwellers. To better understand the scope of ecosystem services, a review is done to examine the extent of the ecosystem services that can be provided by the potential future green land uses and the result is summarised in Table 4-5.

UGS’s ability for food provisioning in urban setting is well documented; Orsini et al. (2014) elaborated that the rooftop gardens alone in the city of Bologna (Italy) has the potential to meet 77% of the inhabitants fresh vegetable demand. Allotments were initially created to provide the financially struggling residents a chance to produce their own food (NSALG, 2020). Communal agricultural greenspaces (e.g. allotments, community gardens, neighbourhood greenspaces) have since helped to ensure long-term food security of the urban population by reducing food dependence from external sources. With climate change increasing the frequency of extreme weather events as well as impacting the weather condition needed for cultivation, exploration of possibilities to use UGSs for food production is becoming a necessity (Barthel & Isendahl, 2013; Lwasa et al., 2014; Speak et al., 2015). Another cause that drives the promotion of food production in the urban environment is to teach and provide the future generation with healthy produces; a Danish company planted fruit trees across day cares in Copenhagen to celebrate its 150th anniversary (BAM Danmark A/S, 2019). One of the concern of producing food in cities has been the pollution concern but a study in Berlin found no additional risk for consuming fruits grown on roadside given they are washed and stored properly (Hoffen & Säumel, 2014). Going a step above, the Copenhagen city council has approved to plant communal fruit trees to be planted in UGSs like park, playground, churchyards, etc. (Agrimag, 2020; Gattuso, 2019). Even when the greenspaces is not directly producing food, UGSs such as grassland and shrubland provides grazing spots and riverbank green provide habitat for aquatic life (Egoh et al., 2011; Ozawa & Yeakley, 2007; Sala & Paruelo, 1997; Wen et al., 2013). Urban greenspaces can provide other provisioning services, providing raw materials such as biomass, especially when fitted with bioenergy crops to produce biofuel or other bio-based products (Haile et al., 2016).

Table 4-5: *Ecosystem services of the studied list of potential future green land uses.*

Building greens	
Provisioning services	
Food	A study on the city of Bologna (Italy) shows roof top gardens could provide more than 12,000 t year^{-1}vegetables satisfying 77 % of the inhabitants' requirements (Orsini et al., 2014).
Regulating services	
Local climate and air quality control	A literature review on urban green roofs find their potential in cooling at street level (0.03–3 C°) and in pollution control such as small particle removal (0.42–9.1 g/m^2 per year)(Francis & Jensen, 2017).
Energy consumption control	Urban green roofs can potentially impact annual energy consumption from 7% increase to 90% decrease (Francis & Jensen, 2017).
Rainwater retention	Extensive green roofs can retain almost 75% of rainwater (Scholz-Barth, 2001; Villarreal & Bengtsson, 2005).
Supporting services	
Biodiversity conservation	Green roofs can provide sites for potential bee conservation in urban areas if planted with native plants and foraging resources designed to accommodate bees (Tonietto et al., 2011).
Bioswale	
Regulating services	
Nutrient cycling and waste-water treatment	A study in residential sites in California (USA) finds bioswales to significantly reduce contaminants from stormwater including suspended solids (81% reduction), metals (81% reduction), hydrocarbons (82% reduction), and pyrethroid pesticides (74% reduction) (Anderson et al., 2016).

Reduction in stormwater runoff	Another study on bioswale on parking lot at Davis (USA) reveals to reduce runoff by 88.8% and total pollutant loading by 95.4% (Xiao & McPherson, 2011).
Riverbank green	
Provisioning services	
Food (indirect)	Riverbank green provides habitat and supports aquatic life (Ozawa & Yeakley, 2007) which in turns supports fishing activities (Ricaurte et al., 2017).
Raw materials	Riverbank greens can support production of vegetative biomass (Koopman et al., 2018).
Regulating services	
Carbon sequestration and storage	A study on the riverbank green in Mexico suggests that it can store 1.5 times more carbon than oak forests (Mendez-Estrella et al., 2017).
Nutrient cycling	Multiple studies Riverbank green acts as a protective buffer between waterbody and land- based activities by filtering nutrients as well as trapping nutrients for groundwater (de Sosa et al., 2018; Hill et al.. 2006; Kauffman et al., 1997; Meek et al., 2010; Mikkelsen & Vesho, 2000; Ozawa & Alan Yeakley, 2007; Pert et al., 2010; Tickner et al., 2001).
Bank stability and flood attenuation	Riverbank green helps in trapping sediment during flooding events and forms soil, slowing and spreading flood water, increasing bank stability and minimising soil loss in watercourse (de Sosa et al., 2018; Kauffman et al., 1997; McKergow et al., 2004; Meek et al., 2010; Mikkelsen & Vesho, 2000; Ozawa & Alan Yeakley, 2007; Pert et al., 2010; Tickner et al., 2001; Zaimes et al., 2007).
Water temperature regulation	Riverbank green assists in regulating the watercourse temperature by providing shading (de Sosa et al., 2018; Naiman et al., 2010; Pert et al., 2010; Pusey & Arthington, 2003).
Supporting services	
Habitat and maintenance of species (Aquatic and terrestrial)	Riverbank green provides habitat and support for aquatic life, refuge for wildlife in urban and rural areas, and contribute to species richness and biodiversity by maintaining wildlife movement corridors (de Sosa et al., 2018; Gray et al., 2014; Matos, Santos et al., 2009; Naiman et al., 2010; Ozawa & Alan Yeakley, 2007; Pert et al., 2010).
Cultural services	
Recreation and aesthetic appreciation	Riverbank green helps in increasing the aesthetic value of agricultural and urban landscapes as well as providing places for outdoor activity (Meek et al., 2010; Postel & Carpenter, 1997).

Culture and sense of place	For the locals of Central Benin, riverbank green is a source of cultural importance and traditional knowledge, provides cultural identity, and a source of belonging (Ceperley, Montagnini, & Natta, 2010; Ricaurte et al., 2017).
Historical park	
Regulating services	
Carbon sequestration and storage	The urban areas covered by parks, gardens, tree-lined avenues, sport fields, and hedges are important sinks for carbon dioxide (CO_2) by storing carbon through photosynthesis to form plant biomass (Gratani et al., 2016).
Cultural services	
Healthy living:	Urban park experience may reduce stress; provide a place to relax, enjoy peacefulness and tranquillity, and rejuvenate for the city inhabitants (Chiesura, 2004a; Gratani et al., 2016; Ulrich, 1981).
Neighbourhood greenspace, allotment and community garden	
Provisioning services	
Food products	Gross benefit from food products per allotment plot in Manchester (UK) can be up to £698 in a year. Apart from plant produce, live stocks such as chickens are also kept in the allotment garden (Speak et al., 2015). Community gardeners in New York city (USA) manage to supply a large share of their households' food product needs with the garden produce (Gregory et al., 2016).
Food security	Urban allotment gardens are an historically important source of urban resilience against food dependence, extreme weather events or even climate change contributing to long-term food security (Barthel & Isendahl, 2013; Lwasa et al., 2014; Speak et al., 2015).
Medicinal herb and tea	Several allotments in Manchester are found to be cultivating medicinal herbs both for medicine and culinary purpose (Speak et al., 2015).
Regulating services	
Soil health	A study in UK shows that soils in allotment gardens have 32% higher soil organic carbon (SOC) concentrations and 36% higher Carbon:Nitrogen ratios than pastures and arable fields (Edmondson et al., 2014).
Stormwater retention	The community gardens of NYC, USA are expected to be retaining 45 million litres of additional stormwater due to its' raise beds (Gittleman et al., 2017).

Supporting services	
Habitat and maintenance of species	A study found that the parks in Manchester (UK) to have about 65% of the species richness of Manchester allotment gardens (Speak et al., 2015). Allotment gardens in Poznan (Poland) also show to have more native varieties of flora (Borysiak et al., 2017). A study in Stockholm (Sweden) found the variability of bumble bee visits in urban allotment gardens to be higher than per-urban ones (Ahrné et al., 2009).
Cultural services	
Nature education	Allotment and community gardens are prime spots for education on nature and sustainable food production techniques among community groups in the cities (Breuste & Artmann, 2015; Chan, DuBois, & Tidball, 2015; Middle et al., 2014; Speak et al., 2015).
Health benefits from physical activities	Allotment and community gardens provide an alternative and more accessible physical activities beneficiary especially for the elderly population (Middle et al., 2014; Speak et al., 2015).
Knowledge production	A study in Sub-Saharan Africa found community clinic gardens to be a place for co-production of knowledge on growing nutritious food by the involvement of multiple stakeholders (Cilliers et al., 2018).
Recreational benefits	The allotment gardens in Poznan (Poland) are treated like recreational retreats during the summer months (Speak et al., 2015). In Germany and Austria, allotment gardens are also considered as recreational areas in planning regulations (Breuste & Artmann, 2015).
Grassland and shrubland	
Provisioning services	
Food, raw materials, medicinal plants	Grasslands are commonly used as grazing fields by many communities as well as providing games for hunt, thatching materials for roofs and walls, medicinal plants and fruits (Dzerefos & Witkowski, 2001; Egoh et al., 2011; Friday et al., 1999; Miller, 2005; Sala & Paruelo, 1997; Wen et al., 2013).
Regulating services	
Carbon sequestration and storage	Grassland in various regions acts as soil carbon storage at the same time providing site for tree plantation to sequester aboveground carbon as well (Farley et al., 2013; Farley et al., 2004; Hofstede et al., 2002; Paul et al., 2002). A study across six European shrubland shows net carbon storage in the systems ranged from 1,163 g C m^{-2} to 18,546 g C m^{-2} (Beier et al., 2009).
Water supply and storage	Grassland play an important role in water supply by mitigating and storing runoff waters (Egoh et al., 2011; Farley et al., 2013; Kotze & Morris, 2001).

Supporting services	
Habitat and maintenance of species	Grassland restorations in China show improved biodiversity by 32.44% (Egoh et al., 2011; White et al., 2000).
Cultural services	
Maintenance of culture and tradition	Alpine grassland plays an important role in Tibetan culture and maintenance of tradition (Dong et al., 2010; Wen et al., 2013).
Meadow orchard	
Provisioning services	
Food provision:	In Berlin, fruit trees are abundantly used for ornamental reason but can be potentially be used for consumption as the fruits are found to pose no additional risk from pollution if washed thoroughly and stored properly (von Hoffen & Säumel, 2014).
Supporting services	
Habitat support	A study suggests that with proper maintenance of living ground cover in almond orchards could provide habitat for pollinators like native bees (Saunders et al., 2013). Orchards, abandoned and functioning, are found to provide habitat and refuge to birds (Myczko et al., 2013).
Biofuel agroforestry	
Provisioning services	
Raw materials (Biofuel and biomass)	Jathropa plantation in a study shows to produce 230kg biodiesel replacement in fossil fuel per hectare as well as producing 4000kg of plant biomass per year (Wani et al., 2012). Agroforestry intercropping of woody and perennial bioenergy crops increases combined biomass yield and reduce the cost of production (Haile et al., 2016).
Regulating services	
Carbon sequestration and storage	In 4 years, Jathropa cultivation is showed to have increased the carbon content by 19% resulting in 25000 kg carbon sequestrated per hectare (Wani et al., 2012).
Nutrient cycling and climate change support	Strategically planted willow buffer can improve the net global warming potential (GWP) and eutrophication potential (EP) of soil as well as cutback nutrient loading to waters (Styles et al., 2016).
Water supply and storage	The water holding capacity of the soil under Jathropa plantation showed to increase by 35% compared to adjacent soil (Wani et al., 2012).

Supporting services	
Habitat and maintenance of species	Agroforestry with combining grass cover and perennial biofuel plantings is expected to support a larger and more diverse bee community as well as many other beneficial insects (Gardiner et al., 2010).
Horticulture	
Provisioning services	
Food and raw materials	Horticulture contributes directly to urban economics through the production and sales of horticulture products (Lohr & Relf, 2014)

UGSs in cities perform many essential regulatory services; extensive green roofs can retain almost 75% of rainwater and at the same time has the ability to moderate urban heat island effect by lowering the street level temperature by 0.03-3 °C (Francis & Jensen, 2017; Gratani et al., 2016; Scholz-Barth, 2001; Villarreal & Bengtsson, 2005). Riverbank greens protects the surface and groundwater from polluted road runoffs by filtering the nutrients while stabilizing the river side and regulating floods (de Sosa et al., 2018; Kauffman et al., 1997; Meek et al., 2010; Mikkelsen & Vesho, 2000). Bioswales are essentially created for their nutrient recycling abilities and they are very effective as one study in Davis (USA) found them to reduce pollutant loading in road runoff water by 95.4% (Xiao & McPherson, 2011). Greenspaces also help in maintaining a healthy soil; urban allotments on average show to have 32% higher soil organic carbon (SOC) concertation than pasture lands (Edmondson et al.2014).

Cities are largely inhabited by humans as they are built to house them in greater concentration but the urban green spaces in the city can provide essential refuge for other species. Urban allotments in Stockholm support a greater variety of bumble bee population than that of the peri-urban areas (Ahrné et al., 2009). Another study in urban allotments' ability to support biodiversity in Manchester (UK) found them to support more species of spontaneous flora than that of urban parks (Speak et al., 2015). Many other UGSs such as green roofs, biofuel plantation, and meadow orchards are found to provide necessary habitat for bumble bees and birds (Gardiner et al., 2010; Myczko et al., 2013; Saunders et al., 2013; Tonietto et al., 2011).

In the present context of the cities, the most important services provided by UGSs are most probably cultural. People living in neighborhood rich in greenspaces tend to be healthier or report themselves as healthier (Maes et al., 2016). Urban greens play an instrumental role ensuring the metal well-being of the residents by providing them with places to relax, reduce stress, and rejuvenate (Chiesura, 2004a; Gratani et al., 2016; Ulrich, 1981). Natural greens like riparian greens and grasslands are found to have traditional and cultural significance while remaining essential recreational outings (Ceperley et al., 2010; Dong et al., 2010; Meek et al., 2010; Postel & Carpenter, 1997; Ricaurte et al., 2017; Wen et al., 2013). Even UGSs that are initially purposed for food provisioning, additionally provides the users to reconnect with nature and learn about sustainable cultivation methods as well as being an option for physical activities (Breuste & Artmann, 2015; Chan et al., 2015; Middle et al., 2014; Speak et al., 2015). Such potentials have been addressed in Germany and Austria where allotments are designated recreational areas (Breuste & Artmann, 2015). There are possibilities of the UGSs having an even broader impact on citizens' well-being but much of the types of greenspaces are simply not investigated well enough to have a better understanding.

5 Discussion and Conclusion

CE is a novel concept, one of the newest in the field of sustainability applications and it is still at a stage of theoretical exploration. Several frameworks and policy instruments have been developed with a degree of variability in terms of the scopes and adaptation of CE. CE is also most probably the only sustainability argument to date that provides a prospect of industrial growth rather than slowing down. This aspect of the concept catapulted its popularity among governmental bodies that despite lack of evidence of CE’s efficiency, has already replaced the waste hierarchy in the EU agenda for sustainability. Now that the reviews of the CE application have started to roll in from various sectors, the initial success promised by CE has started to fade in comparison. However, CE is inherently based on several well-established sustainability measures such as the waste hierarchy, industrial ecology and such, so it is more practical to see CE as a steppingstone that will evolve and adjust over time with specific needs of sustainability adaptations.

CE is readily applicable in industrial processes and product design, and by doing so it opens up a realm of innovation that is necessary to drive the industry forward. The majority of examples of CE application can thus be found on the micro scale and even then, the focus would be at a particular aspect of the product (e.g. packaging) rather than the entire production system. Even though focusing on individual aspect can make it easier to design and assess the impact of implementing CE, the lack of holism can limit the objective of system efficiency making CE vulnerable to the criticism that’s been plaguing most other sustainability concepts. One great aspect of circular strategies, however, is that it can be scaled up or down to fit specific agendas and address a multitude of issues. And its relative novelty along with multifaceted approach (i.e. technical and bio-based) to sustainability adds to the scope of exploration of CE application in various fields. This literature review report used these aspects of CE to explore the opportunities of bio-based production on urban brownfield land.

When a city is considered as an entity, a system in itself, the prospect of implementing CE becomes manifold and the exploration on this field has just started. Most of the examples so far have considered the strategic aspects such as stakeholder involvement and knowledge development, but the approaches are more holistic and wider adaptation of CE strategies can be expected if the implementation gets scaled down from here on speculating further on specific issues moving downwards. Without much literature to depend on, the bio-based CE perspective on soil and land use in cities discussed in this report, a holistic top-down approach similar to this has been adopted. First, land in the urban areas has been explored from the CE perspective and brownfields are identified as the waste of a linear land use system. The prospect of repurposing brownfields for bio-based production is then highlighted and a sustainable alternative for risk management (i.e. GROs) that can be incorporated with the objective. Urban green infrastructures are then discussed as bio-based land use options and several green land uses are elaborated further.

Discussing and identifying products of bio-based land uses in the urban context have been the most challenging part of the review. The benefits that can be derived from the green land uses are not always marketable making their monetisation difficult. The ecosystem services (ES) approach has long been hailed as a premium practice for recognition of non-market goods provided by the ecosystem through their identification, quantitation and valuation. Some of the services, largely provisional such as food crop production and raw materials (e.g. for biofuel), can be directly integrated within CE as their market and value chain is well defined. But it will fail to capture some of the most essential services green land uses provide, especially in the urban areas where their need is intensified by their lack of presence. A more comprehensive outlook for the benefits of urban green land use can be given by integrating ES within CE framework. Unfortunately, such ideas and discussions are yet to be matured in scientific literature. Masi et al. (2018) has discussed ES and the role of wetlands alongside CE arguing that the CE and ES are complimentary because both focuses on resource appreciation in a way. Another review by Kapsalis et al. (2019) investigated the interactions between the principles of ES and the CE from inter-organizational systems perspective and found it challenging to compare due to difficulty in defining products' end of life and quality. The complicacy may have risen due to ES having its roots in linear economy with gross one time valuation as argued by Martins (2016). Nonetheless, ES still remains a practical way of capturing the wide range of benefits that can be derived from urban green spaces. Furthermore, it is essential for addressing the potential of integrating GROs with green land use in retrofitting brownfields and the added benefits of this option compared to 'hard' remediation methods. In this report, ES are therefore elaborated as potential benefits and thus products of bio-based land use in the city context.

The main conclusions drawn from this literature review are:

- CE is the novel concept for practical application of the sustainability principles targeted for industries and policy makers. The outlook of the concept is still in progress as various models, frameworks, and policy briefs are being developed and tested. CE provides an opportunity for systematic rethinking at different scales and can be elaborated to cover issues of both technical and bio-based nature.
- CE application is multifaceted in cities interpreting the urban system as a whole or in parts. CE approaches using the "city as an entity" are mostly strategic and legislative approaches integrating different stakeholders serving specific purposes. Most strategies from macro perspective are in the incubation stage with the prospect of developing over time and practice.
- The micro level approach to cities from the perspective of different essential services are however largely industry oriented. Several of the examples in place are residues of other sustainable practices such as the waste hierarchy, industrial ecology, etc. that are adapted to represent CE strategies rather than rethinking the entire production system.

- Reimaging urban land use from the circular perspective leads us to understand brownfields as the valuable resource of a circular land use system and which may be especially important in supporting the bio-based cycle of CE in cities.
- Brownfields have different policy context if the comparison is drawn between where the term is developed, in the US, and in Europe where several other synonyms for the term in various languages exists. What is common in both contexts are that they have perceived risk of contamination and at present, considered as opportunities for urban regeneration.
- Remediation and repurposing of brownfields can be categorized based on two key determinants: available time and resource. GROs are long term information intensive processes of risk management that prioritise soil health and can be effectively integrated with bio-based green land uses.
- Urban green spaces (UGSs) at brownfields can be considered as possible bio-based land use options in cities where the land is in short supply and green spaces of various size, shape, and use are in increasing demand.
- The multitude of benefits that can be derived from UGSs can best be captured with the ES approach. The bio-based products of UGSs in the urban context are thus elaborated with ES for 14 selected UGS options.

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